ELEMENTARY CHEMICAL CALCULATIONS

MARTIN MEYER

Claremont C. Hoyt.

ELEMENTARY
CHEMICAL CALCULATIONS

ELEMENTARY CHEMICAL CALCULATIONS

BY
MARTIN MEYER, Ph.D.
The College of the City of New York

THIRD EDITION, REVISED

NEW YORK
OXFORD BOOK COMPANY
Educational Publishers

Copyright, 1923, by
OXFORD BOOK COMPANY, Inc.

PREFACE

THE solution of problems is the practical phase of any subject, and, until the student has acquired accuracy and ease in this art, he has not mastered the course. Advanced students in chemistry are frequently handicapped by a total inability to deal with the simplest matters of fundamental theory in a mathematical way. Were it not for the fact that time limitation is already one of, if not the principal of the problems in the teaching of general chemistry, the author would be in favor of making problem work an autonomous division. It is, however, his sincere opinion that problem methods should form an integral part of any course in general chemistry, and his conclusion, based upon several years of teaching experience, that the usual run of texts does not furnish sufficient information for beginners in the science to become proficient in this important matter. For very obvious reasons, this is, of course, not at all an adverse criticism of otherwise excellent text-books.

It has been found expedient to divide the problems into a number of types, and this division is naturally more or less arbitrary. It is adopted nevertheless to avoid the objection, which may be made to almost, if not all texts, of considering the chemical calculations in large, unassimilable doses.

Originality is not claimed in all of the methods of solution. These are based upon chemical principles well-known to all, though in certain cases frequently overlooked, and available in so many treatises that acknowledgment would be futile. The problems themselves have been chosen from all convenient sources, especially from

Regents', College Entrance Board, and college examinations, and a judicious selection has been made from the works of Avery; Barker; Baskerville and Estabrooke; Blanchard and Wade; Baskerville; Bradbury; Brownlee, Fuller, Hancock, Sohon and Whitsit; Hessler and Smith; Holmes; Mellor; Smith; Smith-Kendall and Slosson; Taylor; and several others which contributed a few, in order to secure a wide choice and representative collection. A number of problems may be original.

This little volume is not designed to replace either teacher or text but to accompany any book which may be used. No text-book can replace a good teacher, though it may well amplify the effect of a poor one. In any event, it will furnish sufficient explanatory matter to allow the instructor time to devote to more difficult portions, while assuming that the fundamentals have been comprehended. In outlining the methods the author has attempted to avoid the tendency to make this a text-book in itself and has not given any more of the general theory in any case than a mere statement of the law upon which the problem is based. For further exposition the student should be referred to his own book. It is hoped that the volume will find application, and the author will be pleased to receive criticism and suggestions regarding this first edition.

In concluding, the author wishes to express his warmest appreciation to his colleagues, Professors W. L. Prager, F. E. Breithut, and Mr. B. L. Clarke, and to Mr. Augustus Klock of the Ethical Culture School, for their kindness in reading the manuscript and offering valued suggestions.

New York, Martin Meyer.
May, 1923.

PUBLISHER'S NOTE

Answers to the problems in this book are published in a separate pamphlet.

CONTENTS

CHAPTER PAGE

I. INTRODUCTION; UNITS OF MEASUREMENT 1

II. FORMULÆ AND MOLECULAR WEIGHTS 10

III. PERCENTAGE COMPOSITION 15

IV. CALCULATION OF CHEMICAL FORMULÆ 22

V. EQUATIONS; WEIGHTS FROM EQUATIONS 30

VI. VOLUMES OF GASES 40

VII. WEIGHTS OF GASES 51

VIII. VOLUMES OF GASES FROM EQUATIONS 60

IX. SOLUTIONS 70

X. EXPERIMENTAL DETERMINATION OF MOLECULAR WEIGHT 81

XI. ATOMIC WEIGHTS AND ANALYTICAL CALCULATIONS 89

XII. IONIZATION 101

XIII. ELECTROCHEMICAL PROBLEMS 110

XIV. SPECIAL TYPES 116

APPENDIX

ATOMIC WEIGHTS 125

FOUR-PLACE LOGARITHMS 126

TEMPERATURE CONVERSION TABLES:

Centigrade to Fahrenheit 128

Fahrenheit to Centigrade 129

VAPOR TENSION OF WATER FROM 0–39° C 130

THE METRIC SYSTEM 130

ELEMENTARY CHEMICAL CALCULATIONS

CHAPTER I

INTRODUCTION; UNITS OF MEASUREMENT

One of the greatest difficulties which students appear to find in solving problems of any kind, chemical or otherwise, is their unfamiliarity with the meaning of certain fundamental quantities and the units in which they are expressed. The object of this chapter is to recall a few of these important things.

Units of Length, Area, Volume, and Weight. All scientific measurements are made in the Centimeter-Gram-Second (C.G.S.) system. Those included in the caption of this paragraph are in the **Metric system,** because, with the exception of the units of time, it is a sensible, decimal, and therefore easily computed system, in which the units are interrelated wherever possible; e.g., the unit of weight is the **gram** which is the weight of a cubic centimeter of water at maximum density (4° C.).

In the Appendix, page 134, is a list of the names and magnitudes of the units in the Metric system. The student should learn (*memorize*) these. It will be of some assistance to note that, in general, the names of the units are those of the fundamental unit of that kind with a Latin prefix for a decimal fraction thereof, and a Greek prefix for a decimal multiple.

Unit of weight = **gram** (g.) { 1/1000 g. = 1 milligram (mg.)
1000 g. = 1 kilogram (Kg.)

Unit of length = **meter** (m.) { 1/1000 m. = 1 millimeter (mm.)
1000 m. = 1 kilometer (Km.)

Note the abbreviations.

The student should learn, in addition, a sufficient number of conversion factors to enable him to convert, without reference to a book, any measurement in the English system to any appropriate one in the Metric system and vice versa. Convenient values to remember for this purpose are:

1 inch = 2.54 centimeters
1 kilogram = 2.21 pounds
1 liter = 1.06 liquid quarts

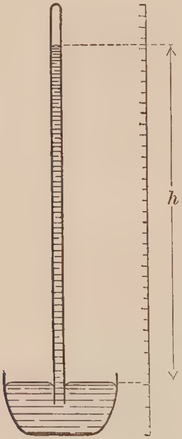

FIG. 1.

Units of Pressure. We frequently have to deal with pressure in chemical problems, generally that of the atmosphere or of other gases. Atmospheric pressure is determined by means of the **barometer,** of which there are several common forms. The most usual laboratory instrument consists of a long, narrow tube which has been completely filled with mercury and then inverted in a bowl of that substance so that no air enters (Fig. 1). Above the mercury in the tube is a vacuum, and hence the pressure per unit area of the mercury column exactly balances that of the atmosphere.

One **atmosphere** pressure is, on the average, about that exerted by a column of mercury 76 centimeters in length, is always taken for this, and, since mercury weighs 13.6 grams per cubic centimeter this is equal to $76 \times 13.6 = 1033$ grams per square centimeter or about 15 pounds per square inch.

To eliminate the bowl of mercury a barometer is sometimes designed as in Fig. 2. A meter stick is mounted alongside the tube, and the barometric reading is then the *difference* between the heights of the two levels (h). Since the volume of mercury increases as the temperature rises, it is necessary, for accurate work, to make a temperature correction which is subtracted from the observed reading. For elementary general chemistry purposes, however, this is unnecessary.

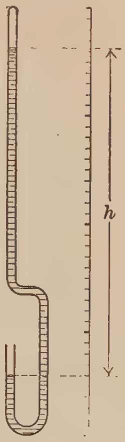

FIG. 2.

Pressure may be expressed in atmospheres, pounds per square inch, grams per square centimeter; in general, *force per unit area;* or in centimeters or millimeters of mercury, in which case it means the pressure exerted by a column of mercury of that height.*

Units of Heat and Temperature. Heat is a thing with which one has also a great deal to do in chemistry as in everyday life. The intensity of heat is called **temperature** and is measured by means of a **thermometer,** a device containing mercury, or any other convenient fluid which varies in volume as the temperature changes. The volume variations are read upon an arbitrary scale and given as the temperature.

In scientific work the **Centigrade Scale** is always employed, except for gases, as we shall see, and upon this scale 0° = 32° F. and 100° = 212° F. One degree Centigrade is therefore equal to 1.8 degrees **Fahrenheit,** the ordinary temperature scale familiar to everyone.

$$C = \tfrac{5}{9}(F - 32)$$

$$F = \tfrac{9}{5}C + 32$$

---

* For certain other matters dealing with gaseous pressures, see the introductory matter to Chapter VI.

where C is the reading on the Centigrade scale and F the reading on the Fahrenheit scale.

In the case of gases, particularly in the solution of problems, temperatures are frequently expressed in degrees **Absolute** (°A. or °K.). The *Absolute degree* is of the same size as the Centigrade degree but the zero point of the scale is different.

Temperature Absolute = Temperature Centigrade + 273.

For chemical work, the unit of quantity of heat is the **calorie.** A calorie is the amount of heat required to raise the temperature of one gram of water one degree Centigrade.

Since the **specific heat** of a substance is the amount of heat necessary to raise the temperature of one gram of that substance one degree Centigrade, the specific heat of water is, by definition, 1.

For engineering and most practical uses, the unit of heat is the **British Thermal Unit** (B.T.U.). This represents the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. It is equal to 252 calories.

Electrical Units. Like heat, electricity is a form of energy. The units which the student of chemistry most frequently has occasion to use are the volt, ampere, ohm, coulomb and watt.

The intensity factor of electrical energy is the electromotive force (E.M.F.), the practical unit of which is the **volt,** an arbitrarily defined magnitude. The unit of electrical current is the **ampere,** a quantity that is legally defined in terms of the chemical effect of the current. A wire conductor through which flows a current of 1 ampere when the potential difference or voltage across its ends is 1 volt, has a resistance of 1 ohm. The resistance of a column of mercury 106.3 cm. long and 1 sq. mm. in cross-section is 1 ohm at 0° C.

Ohm's Law. For any continuous current, electrical circuit, or part of it, the above units are related as follows:

$$E = I \times R$$

where E is the voltage, I the current, and R the resistance in these units.

The capacity factor of electrical energy is the **coulomb.** A current of 1 ampere flowing for 1 second is 1 coulomb. In general, the product of the current in amperes and the time in seconds gives coulombs. 96,500 coulombs of electricity, if passed through an appropriate solution, will liberate 1 equivalent weight (q. v.) of any substance.

The product of volts and amperes gives **watts.** A watt is a unit of power, and is a quantity sufficient to generate 0.24 calorie of heat per second.

Joule's Law. The total energy of a given current in terms of heat is expressed by

$$H = 0.24 I^2 \times R \times t = 0.24 E \times I \times t$$

where H represents the heat in calories, I the current in amperes, R the resistance in ohms, t the time in seconds, and E the electromotive force in volts.

A Few Important Physical Properties.

The **density** of a liquid or a solid is its weight per unit volume. In the Metric system, density is measured in grams per cubic centimeter.

The **specific gravity** of a liquid or a solid is the weight of a given volume compared with the weight of the same volume of water.

$$\text{Specific gravity} = \frac{\text{weight of substance}}{\text{weight of equal volume of water}}$$

Since a cubic centimeter of water weighs one gram, the numerical values of the density and the specific gravity of a substance are the same in the Metric system. The numerical value of the specific gravity of any substance is the same in all systems.

The **volume** of a given weight of material is its weight divided by its density; the weight of a given volume is its volume multiplied by its density:

$$V=\frac{W}{d} \qquad W=V\times d$$

In chemical work, as in other lines of scientific endeavor, we are interested in many properties of materials. The student should always familiarize himself with the definition of, and the units in which a physical property of a substance is expressed by consulting a text-book or, if necessary, an encyclopedia.

PROBLEMS

1. How many cubic centimeters in a liter? In 1 cu. dm.? State the relation between a gram, milligram, decigram, centigram, and kilogram; between a millimeter, centimeter, decimeter, and meter.

2. In what way are the metric units of length, weight, and volume related?

3. Calculate to four significant figures the number of kilograms of water in a cubic foot.

4. Five thousand feet are how many meters?

5. The velocity of light is 186,000 miles per second. Express this value in kilometers.

6. A rectangular water tank 8×4×4 ft. will hold how many liters of water?

7. Change to meters: 5280 ft., 1000 yds., 15 ft. 6 in., 900 in.

8. A sphere with a capacity of 100 liters has a diameter of how many feet?

9. The conical portion of a funnel has a diameter of 25 mm. and is 30 mm. in length (altitude). How many cubic centimeters of liquid can be filtered in three successive portions, assuming the funnel to be filled to the brim in each case? If it takes 45 seconds for the funnel to empty completely, how long will it take to filter 100 cc. of liquid?

10. The radius of the earth is, roughly, 3960 miles, and its

average sp.gr. is 5.5. Assuming it to be a perfect sphere, calculate its weight in kilograms to four significant figures.

11. No. 10 B. & S. copper wire has a diameter of 0.134 in. Calculate its cross-section in square millimeters.

12. Compare the volumes in cubic centimeters of a cube, a cone, and a sphere, the dimensions of which, necessary for the calculations (i.e., edge; diameter and altitude; and diameter, respectively) are 1 in.

13. A cubic foot of water weighs 62.5 lbs. A cubic foot of iron weighs 462.5 lbs. What is the specific gravity of iron?

14. The specific gravity of lead is 11.3. Calculate the weight in kilograms of a cubic foot of lead.

15. The specific gravity of concentrated sulphuric acid is 1.84. If a cubic foot of water weighs 62.5 lbs., how many cubic feet are there in a ton of the acid?

16. What is the weight of 106 cc. of water? Give the volume in cubic centimeters of 30 g. of water. Of 30 g. of platinum (specific gravity 21.5). Of 30 g. of ether (specific gravity 0.72).

17. What is the length of the side of a cube of copper which weighs 10 lbs., if the density of copper is 8.9 g. per cubic centimeter?

18. A pressure of two atmospheres represents how many pounds per square inch?

19. A pressure of 767 mm. represents how many: (*a*) pounds per square inch; (*b*) atmospheres; (*c*) inches of mercury; (*d*) inches of water?

20. How far must a diver be submerged before the pressure upon him is five atmospheres?

21. Explain what is meant by the statement: "The atmospheric pressure to-day is 762 mm." Show how it is possible to express pressure, which is a force, in units of length.

22. If the barometric pressure on a given day is 757.2 mm., give a possible reading of the barometer in Fig. 2.

23. A rectangular block of lead (specific gravity 11.3) $12 \times 4 \times 4$ in. is standing on end on a table. What is the pressure per square inch which it exerts?

24. Two hemispheres making air-tight contact are placed together, and the enclosed air is pumped out. Assuming the

average atmospheric pressure, what force would be required to separate them if they were 2 ft. in diameter?

25. To what temperature Centigrade and Absolute does 212° Fahrenheit correspond?

26. Make a table of Absolute and Fahrenheit temperatures which correspond to the following Centigrade temperatures: −273°, −21°, 0°, 22°, 100°, 500°, 1000°.

27. In a certain part of the United States the average lowest winter temperature is −40° F. and the average highest summer temperature is 120° F. To what range does this correspond in Centigrade degrees?

28. What is meant by the sentence: "The specific heat of copper is 0.093?

29. If the specific heat of copper is 0.093, how much heat would be given off by a strip of copper weighing 30 g. in cooling from 300° C. to 20° C.? This quantity of heat would warm how many grams of water 10° C.?

30. The latent heat of fusion of ice is 79 calories per gram. How many grams of water could be heated from 20° C. to 100° C. by the heat required to melt 1 Kg. of ice?

31. 100 cc. of water at 90° C. and 100 cc. of water at 40° C. are mixed. What will be the temperature of the resulting mixture?

32. If 10 g. of ice are placed in 500 cc. of water at 90° C., what will be the final temperature of the water?

33. How many calories are required to raise the temperature of 500 g. of a substance of specific heat 0.5 from 15° C. to 37° C.?

34. The specific heat of aluminium is 0.217 calorie per gram. How much heat is given off by 10 g. of aluminium in cooling from 300° C. to 20° C.?

35. If 10 g. of aluminium at 300° C. are plunged into a liter of water at 20° C., what will be the final temperature of the water?

36. At $3 per 100 lbs., how much will a block of sulphur 100×50×50m. be worth? The specific gravity of sulphur is 2.05.

37. How many grams of alcohol are there in 100 cc. of a solution which has a specific gravity of 0.9493 and contains 34.77% alcohol?

38. How many pounds per cubic foot does sugar weigh if its specific gravity is 1.61?

39. If gold is worth $20 an ounce, how much is a kilogram of a certain alloy which contains 15% gold worth?

40. Copper has a specific gravity of 8.9. How much do 1000 ft. of No. 14 wire weigh if it is 0.064 in. in diameter?

41. A specimen of a certain mineral weighed 4.93 g. in air and in water it weighed only 3.886 g. What is its specific gravity?

42. A boat which displaces 100 cu. ft. of water has what carrying capacity in kilograms?

43. How many kilograms does a cubic yard of water weigh?

44. A bottle weighs 80 g. when empty; when filled with water it weighs 230 g.; with bromine, 560 g.; with hydrochloric acid, 260 g. What is the specific gravity of the bromine and of the acid? What is the capacity of the bottle?

45. What is the volume occupied by 10 g. of each of the following substances: calcium, density 1.54; lead, density 11.3; iron, density 7.89; magnesium, density 1.74?

46. No. 40 copper wire has a resistance of 0.99 ohm per foot. What is its resistance per meter? What would be the resistance of a wire 93.7 m. in length?

47. A dry cell has a voltage of 2.28 volts. What current will flow during the instant that it is short-circuited by a piece of wire with a resistance of only 0.01 ohm?

48. At 110 volts, how many watts of electrical energy are used up every second by an electric lamp that draws one ampere of current?

49. At 6¢ per Kilowatt-hour, how much does it cost to keep burning for three hours an incandescent lamp that draws 0.4 ampere on a 110-volt line?

50. If an audion tube requires 6 volts and draws 1.1 amperes, what is the resistance of its filament?

51. How much electrical energy is required in charging a 100-ampere-hour radio battery from a 110-volt line? At 6¢ per Kilowatt-hour how much does this electrical energy cost?

52. How much heat does an incandescent lamp which takes 0.4 ampere at 110 volts generate in one minute?

CHAPTER II

FORMULAE AND MOLECULAR WEIGHTS

Chemical formulae are written in accordance with an agreed-upon conventional system of abbreviations, and with the assumptions of the Atomic Theory. A visible specimen of any substance is composed of a very large number of molecules, all of which are alike, and which, in turn, are made up of atoms that may or may not be alike, depending upon the nature of the substance.

Definitions. A *molecule* is the smallest portion of any substance, elementary or compound, which exhibits the specific physical and chemical properties of that substance.

An *atom* is the smallest portion of matter which can exist under ordinary circumstances, and is, for chemical purposes at least, indivisible.

By agreement, we always write *molecular formulae* for substances, that is, formulae which represent the composition of one molecule (and hence of all molecules) of a substance.

The properties of substances depend upon the *number* and *kind* of atoms in their molecules. Thus, O_2 stands for one molecule of the substance whose molecule contains two atoms of the element oxygen (*ordinary oxygen*); O_3 means one molecule of the substance (*ozone*) whose molecule contains three atoms of the element oxygen. These substances differ chemically and physically even though their molecules contain the same kind of atoms because their *number* is different.

HgO (*mercuric oxide*) represents one molecule of the substance whose molecule contains one atom of mercury and one of oxygen; **HgS** (*mercuric sulphide*) represents one molecule of the substance whose molecule has one atom of mercury and one atom of sulphur. These substances differ from each other and from ordinary oxygen because, although the number of atoms in the molecule in each case is the same, the *kinds* differ.

Atoms are very small particles, but they nevertheless have weights which are as characteristic of each element as the density of a larger aggregate of matter, as, for example, lead. In chemistry we do not use the actual weights of atoms, but numbers which are proportional to them, because the latter are easier to ascertain accurately, and are more convenient to use. Thus, when we say that the atomic weight of oxygen is 16, we do not mean that the weight of an atom of oxygen is 16 in any system of units whatsoever; we simply mean that if A is the actual weight of an oxygen atom and B that of a hydrogen atom, then $A : B = 16 : 1.008$, 1.008 being the chemical relative atomic weight of hydrogen.

These relative atomic weights, taken as grams, are the chemical units of weight. The symbol **O** stands, therefore, not only for the element oxygen, and **H** for hydrogen, but also for 16 g. and 1.008 g. of each respectively. These weights are called **gram-atomic weights.**

In the case of a compound substance, the formula represents a **gram molecular weight, molar weight,** or **mole** of that substance, a quantity which we must know how to calculate from the formula.

The molecular weight of a substance is, obviously, an additive property; i.e., the weight of a molecule, relative or absolute, is the sum of the weights of its constituent atoms. Beginners must be careful not to lose sight of this fact when puzzled by the appearance of a complex formula.

Example 1. What is the molar weight of water?

$$H_2O = 2 \times 1.008 + 16 = 18.016$$

Example 2. Calculate the molecular weight of saltpetre.

$$KNO_3 = 39.1 + 14.008 + 3 \times 16 = 101.108$$

Example 3. Calculate the molecular weight of potash alum, $KAl(SO_4)_2,12H_2O$.

KAl $H_{24}O_{12}$

This formula, which appears complex, means exactly the same as if it were written $K\ Al\ H_{24}S_2O_{20}$ (*verify*), but in the broken-up form it expresses a few more chemical facts. Hence,

$$\begin{array}{lll}
K & & = \ \ 39.1 \\
Al & & = \ \ 27.1 \\
H_{24} = 24 \times 1.008 & & = \ \ 24.192 \\
S_2 \ = 2 \times 32.06 & & = \ \ 64.12 \\
O_{20} = 20 \times 16 & & = 320.0 \\
\hline
\text{Molar weight} & & = 474.512
\end{array}$$

PROBLEMS

1. Calculate the molecular weight of CuO, H_2SO_4, $KClO_3$, $ZnCl_2$, $NaOH$.

2. What are the molar weights of the following compounds: CO, CO_2, SO_2, C_2H_5OH, $C_3H_5(OH)_3$, $NaClO_3$?

3. If the atomic weight of oxygen were 8 instead of 16, what would be the molecular weight of $NaCl$?

4. Re-calculate the molecular weights of the substances in problem 2 upon the assumption that the atomic weight of oxygen is 100.

5. The atomic weights in the table on page 125 in this book are calculated on the basis of oxygen equal to 16, which gives

hydrogen an atomic weight of 1.008. What is the change in the molecular weight of HCl if it is calculated upon the assumption that hydrogen is 1.000?

6. If the atomic weight of hydrogen were 10, what would be the molecular weight of $Bi(NO_3)_3$?

Calculate the molecular weights of the substances in the following problems:

7. KCl; NH_4I; CH_3Br; HIO_3; $CuSO_4$.

8. $NaC_2H_3O_2$; $BaCO_3$; $NaMnO_4$; NH_4ClO_4; CdI_2; $BiONO_3$.

9. $LiCl$; $(NH_4)_2CO_3$; $Ca_3(PO_4)_2$; $Al_2(SO_4)_3$; $Mg(C_2H_3O_2)_2$; $Al(NO_3)_3$.

10. $GlCl_2$; $GlSO_4$; $Gl_3(PO_4)_2$; $NaAlO_2$; KH_2PO_4; $Cu_2(NH_3)_2SO_4$.

11. $LiBrO_3$; NH_4MnO_4; $MgNH_4PO_4$; $Mg_2P_2O_7$; $Ba(C_2H_3O_2)_2$; $SrSO_4$; NH_4I.

12. $BaSeO_4$; $Zr(SO_4)_2$; $Mn_3(PO_4)_2$; $(NH_4)_3PO_4,12MoO_3$; $MgNH_4AsO_4$; $Ti_2(SO_4)_3$.

13. CrO_2Cl_2; $COCl_2$; $C_6H_5NH_2$; $C_{12}H_{22}O_{11}$; CaS; $Ce(SO_4)_2,4H_2O$.

14. $Ce(NO_3)_4$; $Pb(C_2H_3O_2)_2,3H_2O$; $MgNH_4PO_4,6H_2O$; $MgBr_2,6H_2O$; $CaSO_4,2H_2O$; $CaH_4(PO_4)_2,H_2O$; $AlCl_3,6H_2O$.

15. $NaAl(SO_4)_2,12H_2O$; Hg_2CrO_4; $Ni(NH_4)_2(SO_4)_2,6H_2O$; $Ni(CN)_2,4H_2O$; $NiCl_2,NH_4Cl,6H_2O$; $H_2C_2O_4,2H_2O$.

16. $NaFe(CN)_5NO,2H_2O$; $Na_2MoO_4,2H_2O$; $H_{10}Sn_5O_{15}$; $UO_2(HPO_4)_2,4H_2O$; $H_4V_2O_7$; $YtCl_3,6H_2O$; $2ZnSO_3,5H_2O$.

17. $KCr(SO_4)_2,12H_2O$; $(NH_4)_3AsO_4,3H_2O$; Sb_2S_3; $Sb_2(SO_4)_3$; $Ca(H_4PO_2)_2$; $LiHCO_3$.

18. $2NiCO_3,3Ni(OH)_3,4H_2O$; H_2MoO_4,H_2O; K_2PtCl_6; $Cu(NH_3)_4SO_4$; $Na_2Cr_2O_7,2H_2O$; $Na_2H_2Sb_2O_7,H_2O$; $Na_4Fe(CN)_6,12H_2O$.

19. $Na_2B_4O_7,10H_2O$; WCl_3; H_2WO_4; $YbCl_3,6H_2O$; $Yb_2(SO_4)_3$; $NaC_7H_5O_2$.

20. $MgCl_2,2Mg_3B_8O_{15}$; $K_4Fe(CN)_6$; $NaAu(CN)_2$; Ca_2PbO_4; $Fe(CO)_5$; $4KNO_2,Ni(NO_2)_2$; K_3IrCl_6; Na_2PdCl_4.

21. $KHZnO_2$; $Te_2O_3(OH)NO_3$; $Cu_2Fe(CN)_6$; $H_2Al_2(SiO_4)_2,H_2O$; $4Ag_2S,GeS_2$; $GeHCl_3$.

22. $Cu_4(OH)_6Cl_2,H_2O$; $CaF_2,3Ca_3(PO_4)_2$; $Mg_3Ca(SiO_3)_4$; Ag_2S; $K_2Al_2(SO_4)_4,4Al(OH)_3$; $Cu_3(OH)_2,(CO_3)_2$.

23 $MgCl_2KCl,6H_2O$; Zn_2SiO_4,H_2O; $2CaO,3B_2O_3,5H_2O$; $2UO_3,V_2O_3,K_2O,3H_2O$; $Gl_3Al_2(SiO_3)_6$.

24. $MgCa(CO_3)_2$; $3MgO,4B_2O_3,MgCl_2$; Al_2O_3,H_2O; $(MgCa)_3Al_2(SiO_4)_3$; $Zn(AlO_2)_2$; $NiMgSiO_4$.

25. $Zn(FeO_2)_2$, $K_2SO_4,MgSO_4,MgCl_2,6H_2O$; $Cu_2(OH)_2CO_3$; $(KNa)H_2Al_3(SiO_4)_3$, $FeAsS$; Mg_2SiO_4.

26. $(AuAg)Te_2$; $(MgFe)Si_2O_7,2H_2O$; $H_2Mg_3(SiO_3)_4$; $CaCl_2,MgCl_2,12H_2O$; $NaCaB_5O_9,8H_2O$; $(FeMn)WO_4$.

27. H_3PO_2; PCl_3; PCl_5; $POCl_3$; $Mn_3(PO_4)_2$; $Ca(HC_2O_4)_2$; $HClO_3,7H_2O$; $Ce_2(CO_3)_3,7H_2O$; $CrSO_4,7H_2O$.

28. $Co(CO)_4$; Hg_2PO_4; $Pt(OH)_4$; $Pt(SO_4)_2,4H_2O$; $KSbO_3$; PtS_2; $KSbOC_4H_4O_6,\frac{1}{2}H_2O$.

29. $PrCl_3$; Pr_2O_3; H_2SiO_3; $Ru(OH)_3$; $Na_2HPO_4,12H_2O$; Tl_3PO_4.

30. $Zr(NO_3)_4,5H_2O$; $Ni(NH_3)_6Cl_2$; $(VO)_2(SO_4)_3$; $Zn_2Fe(CN)_6,3H_2O$; $2Co(NO_2)_3,6KNO_2,3H_2O$.

31. $KHgCl_4,7H_2O$; K_2HgI_4; $Hg_2(N)NO_3$; $K_2SO_4,Al_4(OH)_6(SO_4)_3$; $SnO(OH)_2$.

32. Na_2SnF_6; $(NH_4)_2SnS_3$; $Pb_2O(OH)_2$; $K_2PbO_3,3H_2O$; $Zn(NO_3)_2,6H_2O$.

33. $Pr_2(SO_4)_3$; $PrCl_3$; BN; $BrCl,10H_2O$; $HBrO_3$; $Cd_2B_2W_9,O_{32},18H_2O$.

34. $3CdSO_4,8H_2O$; $CsC_2H_3O_2$; Cs_2CO_3; $Ba(MnO_4)_2$; $CaBr_2,6H_2O$.

35. $Al(C_2H_3O_2)_3$; BaS_5O_5; HSO_3Cl; $Na_2H_3IO_6$; Mg_2Si; CaC_2; $B(OH)_3$.

36. $ThSiO_4$; $Th(NO_3)_4,6H_2O$; $Bi(OH)_2NO_3$; NH_4VO_3; $Na_3SbS_4,9H_2O$; $NH_4Fe(SO_4)_2,12H_2O$.

37 $TmCl_3$; $Yt_2(SO_4)_3,8H_2O$; $Yb(NO_3)_3$; $LuBr_3$.

38. $DyCl_3$; $Tm_2(SO_4)_3$; $EuPO_4$; $Er(NO_3)_3$; La_2O_3.

39. $Gd_2(SO_4)_3$; $SaBr_3$; $SaPO_4$; Se_2O_3; NdI_3.

40. Ga_2O_3; $Ga_2(SO_4)_3$; $InCl$; $InCl_3$; $In_2(SO_4)_3$.

41. TlO_2H; $Ga(OH)_3$; $HoCl_3$; $Lu_2(SO_4)_3$.

42. K_2RuCl_6; $Tm(NO_3)_3$; $(NH_4)_3IrCl_6$; $Rh_2(SO_4)_3$.

43. $Pd(NO_3)_2$; GeO_2; $GeOCl_3$; $Ce_2(CO_3)_3,5H_2O$.

CHAPTER III

PERCENTAGE COMPOSITION

According to Dalton's *Law of Constant Proportions*, all specimens of the same substance have identically the same composition by weight. Since we write formulae in accordance with the Atomic Theory, from the conventions used in writing formulae, the composition by weight of any substance is really inherent in, and expressed by its molecular formula.

We have agreed, for instance, that H_2O shall stand for 1 gram molecular weight, or 18.016 g. of water. But the formula tells us that every 18.016 g. of water contain 2 gram-atoms, or 2.016 g. of hydrogen, and 1 gram-atom, or 16 g. of oxygen, which is the composition by weight of the gram molecular weight of the compound.

The gram molecular weight is a different number for every substance. We usually express the composition of substances in a common unit of parts per hundred, that is, per cent.

Furthermore, unless otherwise indicated, the percentage composition of a substance means always the elementary percentage composition, or per cent of each element in the compound. In the case of water (H_2O) then, the percentage composition is:

$$H = \frac{2.016}{18.016} \times 100 = 11.19\%$$

$$O = \frac{16}{18.016} \times 100 = 88.81\%$$

Method. *Divide the total expressed weight of each element in the molecule by the total gram molecular weight of the compound, and multiply by* 100, *to convert to per cent.*

Example. What is the percentage composition of saltpetre (KNO_3)?

$$\text{Mol. wt. of } KNO_3 = 39.1 + 14.008 + 48 = 101.108$$

$$K = \frac{39.1}{101.108} \times 100 = 38.67\%$$

$$N = \frac{14.008}{101.108} \times 100 = 13.85\%$$

$$O = \frac{48}{101.108} \times 100 = 47.48\%$$

It is sometimes desirable to calculate the percentage composition of a substance in terms of substances which are not elements. In such a case, rewrite the formula, if necessary, to make it *appear* to contain the substance or substances in question, and then employ their partial molecular weights in calculating, just as you would in the case of the atomic weights of elements.

Example 1. What is the percent of water in potash alum, $KAl(SO_4)_2,12H_2O$?

$$\text{Molecular weight of } KAl(SO_4)_2,12H_2O = 474.512$$

$$\text{Per cent } H_2O = \frac{12 \times 18.016}{474.512} \times 100 = 216.192 \times 100 = 45.56\%$$

Example 2. Calculate the weight of phosphorus pentoxide (P_2O_5) in 1 ton of phosphoric acid (H_3PO_4).

Here we must double the formula:

$$2H_3PO_4 = 3H_2O,P_2O_5 \qquad = 196.168$$

Hence, $$P_2O_5 = \frac{142.12}{196.168} \times 100 = 72.43\%$$

One ton or 2000 pounds of phosphoric acid will therefore contain 2000×0.7243 or 1448.6 pounds of phosphorus pentoxide.

Alternative Method.—This type of problem may also be solved by a proportion method. In finding the percentage compositions of water, we have:

Molar weight of $H_2O = 18.016$

Weight of hydrogen in the molecule $= 2.016$

Let x = per cent of hydrogen. We then have by Dalton's Law:

$$2.016 : 18.016 = x : 100 \quad . \; . \; . \; . \; . \; . \quad (1)$$

Solving,
$$x = \frac{2.016 \times 100}{18.016} = 11.19\%$$

In this case the per cent of oxygen could be found by difference. If the compound contains more than two elements, the per cent of each would be found by a series of proportions such as (1).

Method. (1) *Determine the molecular weight of the compound and the total weights of each element or radical in the molecule.*

(2) *Represent the per cent of each element or radical by an appropriate letter.*

(3) *Make a series of proportions in this order:*

$$\frac{\text{Total weight of element or radical}}{\text{Gram molecular weight}} = \frac{x}{100}$$

(4) *Solve for each per cent.*

In some respects this method is more easily understood than the first. Apply it to the potash alum problem.

PROBLEMS

1. Calculate the percentage composition of (*a*) mercuric oxide, HgO; (*b*) mercuric chloride, $HgCl_2$; (*c*) potassium

chlorate, $KClO_3$; (*d*) manganese dioxide, MnO_2; (*e*) potassium nitrate, KNO_3.

√ 2. Determine the per cent of each element in the following compounds: (*a*) water, H_2O; (*b*) mercurous chloride, $HgCl$; (*c*) sodium chloride, $NaCl$; (*d*) nitric acid, HNO_3; (*e*) cane sugar, $C_{12}H_{22}O_{11}$.

3. What weight of hydrogen is present in 1 ton (English) of pure nitric acid?

√ 4. What are the respective percentages of iron in ferrous chloride ($FeCl_2$) and ferric chloride ($FeCl_3$)?

5. Compare the percentages of oxygen in the following compounds: potassium bromate, $KBrO_3$; barium peroxide, BaO_2; potassium nitrite, KNO_2.

6. At the same price per pound, which would be the cheaper source of oxygen: potassium chlorate, $KClO_3$, or potassium bromate, $KBrO_3$?

7. One gram of potassium permanganate ($KMnO_4$) contains what weight of each of the elements?

8. Calculate the per cent of iron in each of the following important ores: hematite, Fe_2O_3; magnetite, Fe_3O_4; siderite, $FeCO_3$; limonite, $Fe_2O_3,3H_2O$.

9. If magnetite were selling for $5.25 per ton, what would be the probable costs per ton of the other three ores mentioned in problem 8?

10. Calculate the per cent of water in blue vitriol, $CuSO_4,5H_2O$.

11. What per cent of water is present in green vitriol, $FeSO_4,7H_2O$; Glauber's salt, $Na_2SO_4,10H_2O$; hydrated cadmium sulphate, $CdSO_4,4H_2O$?

12. Compare the percentages of water in the two alums: potash or ordinary alum, $KAl(SO_4)_2,12H_2O$, and chrome alum, $KCr(SO_4)_2,12H_2O$.

13. What weight of copper oxide can be obtained from 1 Kg. of cupric nitrate, $[Cu(NO_3)_2]$?

14. A sample of washing soda has the composition represented by the formula $Na_2CO_3,10H_2O$. What per cent is water? If it sells for 10¢ a pound, what are you actually paying for the essential constituent?

15. When 14.3 g. of a certain hydrate were heated, 9 g. of water were lost. Calculate the percentage loss.

16. If Chilean saltpetre is 96.4% pure, determine the weight of Na_2O and N_2O_5 per kilogram.

17. Show that the two hydrocarbons, acetylene, C_2H_2, and benzene, C_6H_6, have the same percentage composition.

18. Which would be cheaper, borax, $Na_2B_4O_7,10H_2O$, at 6¢ a pound, or the anhydrous material at 10¢?

19. What decimal fraction of the compound magnesium pyrophosphate, $Mg_2P_2O_7$, is magnesium oxide, MgO?

20. Calculate the weight of sulphate radical, SO_4, in 1 g. of barium sulphate, $BaSO_4$.

21. What is the per cent of phosphorus in calcium phosphate, the composition of which may be represented by $Ca_3(PO_4)_2$?

22. What weight of iodine could be obtained by completely decomposing 100 g. of potassium iodide, KI?

23. What weight of phosphorus might be obtained from 100 tons of bone ash containing 85% of calcium phosphate, $Ca_3(PO_4)_2$?

24. The average human skeleton weighs about 25 lbs. and contains 58% of calcium phosphate. What weight of phosphorus does it contain?

25. What weight of barium sulphate, $BaSO_4$, contains 5 g. of sulphur?

26. What is the ratio of one part of hydrogen to chlorine in hydrogen chloride?

27. What is the ratio of oxygen to one part of chromium in potassium dichromate, $K_2Cr_2O_7$?

28. What is the ratio of oxygen to one part of nitrogen in nitric acid?

29. Compare the ratios of oxygen to one part of nitrogen in the following compounds: nitroglycerine, $C_3H_5N_3O_9$; T.N.T., $C_7H_5N_3O_6$; picric acid, $C_6H_3N_3O_7$.

30. What weight of mercuric oxide must be decomposed to furnish 10 g. of oxygen?

31. What are the percentages of chlorine in methyl chloride,

CH_3Cl; methylene chloride, CH_2Cl_2; chloroform, $CHCl_3$; carbon tetrachloride, CCl_4?

32. What weight of N_2O_5 is present in 100 g. of nitric acid solution which contains 68% of nitric acid by weight?

33. How much aluminium may be obtained from 1000 Kg. of an ore which is 85% bauxite, $Al_2O_3,2H_2O$?

34. Calculate the decimal fraction of phosphorus pentoxide, P_2O_5, in magnesium ammonium phosphate, $MgNH_4PO_4$.

35. Determine the decimal fraction of chlorine in silver chloride, AgCl.

36. What are the weights of the hydroxyl radical, OH, in 1 g. of each of the following substances: sodium hydroxide, NaOH; potassium hydroxide, KOH; barium hydroxide, $Ba(OH)_2$; bismuth hydroxide, $Bi(OH)_3$?

37. Calculate the weight of molybdenum in 5 g. of each of the following: $MoCl_4$, MoO_2, Mo_2O_3, MoS_2, MoS_3.

38. What is the per cent of osmium in each of the following compounds: $OsCl_3$, OsO_4, OsS_2, OsS_4?

39. What is the per cent of potassium in potassium chloroplatinate, K_2PtCl_6?

40. Determine the composition of potash alum, $KAl(SO_4)_2,12H_2O$, in terms of K_2O, Al_2O_3, SO_3, and H_2O.

41. Compare the weights of sulphur combined with one part of oxygen in the following compounds: H_2SO_4, $H_2S_2O_7$, H_2SO_3, and $H_2S_2O_8$.

42. Compare the weights of chlorine combined with one part of mercury in mercurous chloride, HgCl, and mercuric chloride, $HgCl_2$.

43. Compare the weight of chlorine combined with eight parts of oxygen in each of the following compounds: HClO, $HClO_2$, $HClO_3$, $HClO_4$.

44. What is the per cent of iron in each of the compounds $Fe_3[Fe(CN)_6]_2$ and $Fe_4[Fe(CN)_6]_3$?

45. Determine the composition of cupric phosphate, $Cu_3(PO_4)_2,3H_2O$, in terms of CuO, P_2O_5, and H_2O.

46. Which of the acids, hydrochloric, HCl, sulphuric, H_2SO_4, or phosphoric, H_3PO_4, contains the greatest per cent of hydrogen?

47. A certain mineral contains 90% of copper sulphide, CuS. What weight of it will contain 100 g. of copper?

48. Calculate the percentage composition of the mineral $Mg_3Al_2(SiO_4)_3$ in terms of MgO, Al_2O_3, and SiO_2.

49. Calculate the percentage composition of Scheele's Green, $CuHAsO_3$, in terms of CuO, H_2O, and As_2O_3.

50. What is the per cent of hydrogen in each of the following compounds: acetylene, C_2H_2; ethylene, C_2H_4; ethane, C_2H_6?

51. If tin is worth 38¢ a pound, how much is the metal in a kilogram of an ore which is 81% cassiterite, SnO_2, worth?

52. Determine the per cent of manganese oxide in each of the following compounds: $MnNH_4PO_4,H_2O$; $MnCO_3$; $Mn(NO_3)_2,6H_2O$.

53. Calculate the per cent of mercuric oxide (HgO) in the following compounds: $Hg_3(AsO_4)_2$; $Hg(NO_3)_2,H_2O$; $Hg(OH)_2$.

54. What is the per cent of NiO in the following compounds: $NiCO_3$, $Ni(C_2H_3O_2)_2$, $NiSO_4$?

55. How many grams of each of the following compounds contain 1 g. of lead: PbO_2, Pb_3O_4, $PbSO_4$, PbO?

56. What weight of each of the following contains 1 g. of sulphur trioxide: $FeSO_4$; $Fe_2(SO_4)_3$; Hg_2SO_4; $HgSO_4$?

57. Compare the weights of sodium hydroxide, $NaOH$; potassium hydroxide, KOH; and barium hydroxide, $Ba(OH)_2$; which contain 5 g. of the hydroxyl radical.

58. Five grams of ammonia contain enough nitrogen to make what weight of nitric acid?

59. One pound of iron pyrites, containing 90% FeS_2, contains sufficient sulphur to make what weight of sulphuric acid?

CHAPTER IV

CALCULATION OF CHEMICAL FORMULAE

Dalton's Law furnishes a basis for the most important of fundamental chemical calculations. To the law as stated in the preceding chapter, we can add the important corollary from the Atomic Theory that the composition by weight of any compound is representable by numbers which are the *products* of the *atomic weights* of the constituent elements and *small integers*.

In the preceding chapter we have been interested in determining the percentage composition of compounds from their formulæ. Since the percentage composition of a compound is a series of values which is readily determined experimentally by analytical procedures, the converse of this is therefore an even more important problem, easily solved by reference to Dalton's Law and the corollary just given.

Suppose that a substance is composed of 11.19% hydrogen and 88.81% oxygen. How can we determine its formula? By Dalton's Law every portion of this compound must have the following ratio by weight:

$$\mathrm{H} : \mathrm{O} = 11.19 : 88.81.$$

By the corollary, $11.19 : 88.81 = a \times 1.008 : b \times 16.$

This expression, where a and b are whole numbers, must be an identity. This is equivalent to saying that the formula of the substance must be H_aO_b, where the subscript letters have the same values as in the identity. But, if the expression is an identity, similar terms are equal and, therefore, $a \times 1.008 = 11.19$

or, $$a = \frac{11.19}{1.008} = 11.10$$

and, $b \times 16 = 88.81$

or, $$b = \frac{88.81}{16} = 5.55$$

a and b, however, must be whole numbers and in this case, the very first, they have come out decimal fractions. It is evident that in any numerical example they will, in general, be the required whole numbers only if the composition given is that of the molecular weight of the substance, which usually is unknown. In any case, the quotients obtained by dividing the per cents of the constituents by their atomic weights will be proportional to the true whole numbers. To find these, it is necessary only to take the highest common factor, which is usually apparent on inspection.

In this case the highest common factor is evidently 5.55. Dividing each quotient by this, we observe that $a = 2$ and $b = 1$. The formula is therefore H_2O.

Method. (1) *Divide the number representing the weight of each element in the sample (not necessarily the per cent) by the atomic weight of the element.*

(2) *Find the highest common factor of these quotients and divide each by it.*

(3) *Write the resulting whole numbers as the subscripts of the symbols of the respective elements in the formula.*

If the composition of the substance is given in terms of groups of elements or radicals, their partial molecular weights may be employed like the atomic weights of elements, just as in determining percentage composition.

The formula of a substance obtained by this method is always the simplest or **empirical** formula and the correct one may be some multiple of this. We cannot determine from the percentage composition alone whether the formula for water is H_2O, H_4O_2, or H_6O_3, or even some higher multiple. The true formulæ can be really ascertained only if, in addition, the molecular weight is also known.

In solving this type of problem students are prone to arithmetical errors. Some of the commoner ones may be avoided by observing the following simple precautions:

The work should always be arranged in the schematic form given in the examples solved below, and all quotients should be calculated accurately to three significant figures.

The highest common factor is generally obvious upon inspection as the smallest quotient, or one-half, or one-third of it, but in any event the highest common factor chosen should agree to at least two significant figures, exactly. In solving a problem relating to the elements *A* and *B* a student might find, as an illustration, that the first quotients were respectively 0.91 and 1.20. The tendency is to think: "0.91 is very nearly 1, let's call it that; 1.20 is very nearly 1, let's call it that; the highest common factor is 1, and the formula of the compound is *AB*." This is too careless. A better highest common factor would be 0.30, and the formula, A_3B_4.

An over-conscientious student might make the opposite error and attempt to find a highest common factor which agreed too accurately, eventually arriving, in this case, at 0.01, which would give the equally incorrect formula $A_{91}B_{120}$. This formula is much too complex, for with substances whose formulæ are actually as large as that, this method is not reliable because of the possibilities of experimental error in actual practical work.

Example 1. A substance has the following percentage composition: Na = 32.49%, S = 22.56%, O = 45.04%. Find its simplest formula.

Element	*Composition*	*At. Wt.*	*Quotient*	*Subscript*
Na	32.47	23.00	1.41	2
S	22.56	32.06	0.70	1
O	45.04	16.00	2.81	4

H.C.F = 0.70

Formula = Na_2SO_4

Example 2. 1.0000 g. of a certain substance contains 0.7908 g. of $CaSO_4$, and 0.2092 g. of water. Calculate the formula.

Substance	*Composition*	*Mol. Wt.*	*Quotient*	*Subscript*
$CaSO_4$	0.7908	136.13	0.00581	1
H_2O	0.2092	18.016	0.0116	2

H.C.F = 0.00580 Formula = $CaSO_4,2H_2O$

PROBLEMS

1. Determine the formula of the substance which contains 2.74% of hydrogen and 97.26% of chlorine.

2. One gram of a certain substance contains 0.3043 g. of nitrogen and 0.6957 g. of oxygen. What is its formula?

3. A compound, upon analysis, shows the following composition: carbon, 40.00%; hydrogen, 6.67%; oxygen, 53.33%. Derive its simplest formula and write also two other possible formulæ.

4. What is the simplest formula of the substance 2 g. of which contain 0.8814 g. of mercury and 1.1186 g. of iodine? Give two other formulæ which also represent substances of the same composition.

5. What is the formula of the substance 5 g. of which contain 2.000 g. of calcium, 0.600 g. of carbon, and 2.400 g. of oxygen?

6. A substance contains 52.35% of potassium and 47.65% of chlorine. What is its empirical formula?

7. Calculate the simplest formula of the compound which has the following percentage composition: potassium, 45.9%; nitrogen, 16.5%; oxygen, 37.6%.

8. The mineral cryolite has the following percentage composition: sodium, 32.9%; aluminium, 12.9%; fluorine, 54.2%. What is its empirical formula?

9. When 1 g. of sodium burns in oxygen it produces 1.7 g. of the oxide. What is the formula of the latter?

10. A compound upon analysis is found to contain: calcium, 29.40%; sulphur, 23.56%; oxygen, 47.04%. What is its formula?

11. What is the formula of the chloride of magnesium if 1 g. contains 0.7443 g. of chlorine?

12. Find the empirical formula of the substance which has the following percentage composition: potassium, 26.585%; chromium, 35.390%; oxygen, 38.025%.

13. It was found by analysis that 1 g. of a substance contained sodium, 0.3243 g.; sulphur, 0.2255 g.; and oxygen, 0.4502 g. What is the simplest formula of the substance?

14. A certain salt contains 9.09% of nitrogen, 20.77% of oxygen, and 70.13% of silver. What is its simplest formula?

15. Calculate the formula of the substance which has the following percentage composition: oxygen, 38.1%; hydrogen, 0.8%; phosphorus, 24.6%; sodium, 36.5%.

16. The atomic weight of a metal is 56. An oxide of this metal is found to consist of 53.8% of the metal and 46.2% of oxygen. Calculate the formula of the oxide.

17. Gypsum is a hydrate of calcium sulphate, $CaSO_4$. If 6 g. of gypsum, when heated, lose 1.256 g. of water, what is the formula of the hydrate?

18. A certain gas shows upon analysis to contain 46.5% of carbon and 53.85% of nitrogen. Its molecular weight is found to be 52. What is its correct formula?

19. One gram of a gas contains carbon, 42.8%, and oxygen, 57.1%. Its molecular weight is found to be 28. What is its correct formula?

20. It is found that a sample of gas contains 27.27% of carbon and 72.73% of oxygen, while its molecular weight is 44. What is its true molecular formula?

21. The composition of a compound is: barium, 46.12%; sulphur, 21.54%; oxygen, 32.32%. What is its simplest formula?

22. What is the formula of the compound 1 g. of which contains 0.3872 g. of calcium, 0.2000 g. of phosphorus, and 0.4128 g. of oxygen?

23. From 1 g. of one of the oxides of lead 1.269 g. of lead sulphate can be obtained. Which oxide of lead is it?

24. A salt shows the following composition by weight: silver, 56.4%; chlorine, 18.52%; oxygen, 25.08%. What is its formula and the formula of the acid from which the salt is derived?

25. Anhydrous sodium carbonate has the formula Na_2CO_3. If 10 g. of the crystallized salt lose 6.29 g. of water on heating, how many molecules of water of hydration were present?

26. A compound has a molecular weight of 72. Its composition by weight is carbon, 83.33% and hydrogen, 16.67%. Find its correct formula.

27. For what simplest formula does the following composition by weight stand: carbon, 10.04%; hydrogen, 0.84%; chlorine, 89.12%? If the molecular weight of the substance in question is 119.5, is this formula correct?

28. A certain gas consists of nitrogen, 63.64%, and oxygen, 36.36%. What is its simplest formula? Is this formula correct if the molecular weight of the gas is found to be 44?

29. Upon analysis, a compound is found to contain in every 100 parts 52.17 parts of carbon, 13.04 parts of hydrogen, and 34.78 parts of oxygen. What is the correct formula if the molecular weight of the substance is 46?

30. Anhydrous zinc sulphate has the formula $ZnSO_4$. If the crystallized salt loses 43.8% of its weight on heating, what is its formula?

31. Nine grams of a substance contain 4.2237 g. of silicon and 4.7763 g. of oxygen. What is the formula of the substance?

32. Eight grams of a substance are found to contain 6.8024 g. of silver and 1.1976 g. of fluorine. What is its formula?

33. Determine the correct formula of the substance whose molecular weight is 188 and whose percentage composition is: carbon, 12.77%; hydrogen, 2.12%; bromine, 85.11%.

34. Determine the formula of the substance whose percentage composition is: potassium, 42.41%; iron, 15.22%; carbon, 19.56%; nitrogen, 22.81%.

35. Find the formula of the compound every gram of which

contains 0.0102 g. of hydrogen, 0.3906 g. of potassium, 0.1199 g. of carbon, and 0.4795 g. of oxygen.

36. Derive the formula of the substance whose percentage composition is: lead, 63.61%; carbon, 14.62%; hydrogen, 1.98%; and oxygen, 19.79%.

37. What is the simplest formula of the substance 27 g. of which gave upon analysis: 2.64 g. of magnesium, 3.51 g. of sulphur, 7.02 g. of oxygen, and 13.83 g. of water?

38. Find the formula of the substance which contains in every gram 0.1600 g. of potassium, 0.4041 g. of platinum, and 0.4359 g. of chlorine.

39. A salt of nickel contains 25.32% of nickel, 44.09% of ammonia, and 30.59% of chlorine. What is its formula?

40. What is the formula of the salt which contains 49.96% of the radical (VO) and 50.04% of the radical (SO_4)?

41. Determine the formula of the substance which has the following percentage composition: zinc, 19.73%; iron, 16.86%; carbon, 21.73%; nitrogen, 25.37%; water, 16.31%.

42. One gram of a certain compound contains 0.1650 g. of sodium, 0.4259 g. of tin, and 0.4091 g. of fluorine. What is its formula?

43. What is the empirical formula of the substance which contains nitrogen, 11.15%; hydrogen, 3.21%; tin, 47.29%; sulphur, 38.35%?

44. What is the formula of the compound which contains 49.44% of praseodymium, 16.88% of sulphur, and 33.68% of oxygen?

45. Determine the simplest formula of the compound having the following percentage composition: sodium, 16.92%; hydrogen, 1.11%; iodine, 46.67%; oxygen, 35.40%.

46. A well-known mineral analyzes to the composition indicated by the following percentages: magnesium chloride, 34.27%; potassium chloride, 26.83%; water, 38.90%. Determine its empirical formula.

47. What is the formula of thorium silicate if 1 g. of the compound contains 0.7152 g. of thorium, 0.0871 g. of silicon, and 0.1972 g. of oxygen?

48. An important ore of tungsten contains 18.38% of iron, 60.56% of tungsten, and 21.06% of oxygen. To what empirical formula does this correspond?

49. Calculate the formula of the substance 10 g. of which yielded 0.9940 g. of potassium, 2.552 g. of mercury, and 6.454 g. of iodine.

50. Calculate the formula of the substance having the following percentage composition: copper, 27.90%; ammonia, 29.91%; sulphur, 13.44%; oxygen, 28.75%.

51. To what formula do the following percentages correspond: mercury, 84.07%; nitrogen, 5.87%; oxygen, 10.06%?

52. What is the formula of the mineral which has the composition: K_2O, 14.01%; Al_2O_3, 30.38%; SO_3, 47.58%; H_2O, 8.03%?

53. What is the formula of the mineral which has the following composition: K_2O, 12.67%; As_2O_5, 32.41%; H_2O, 11.65%; MoO_3, 43.27%?

54. What substance corresponds to the following percentage composition: potassium, 23.00%; antimony, 37.86%; sulphur, 18.89%; oxygen, 7.04%; and water, 13.20%?

CHAPTER V

EQUATIONS; WEIGHTS FROM EQUATIONS

A chemical equation is a series of chemical symbols so arranged as to express a chemical fact. In conjunction with the conventions that are used in writing formulæ, equations really tell a great many more things than are at first obvious to the elementary student. Consider the equation:

$$2KMnO_4+16HCl \rightleftharpoons 2KCl+2MnCl_2+8H_2O+\uparrow 5Cl_2$$

This equation states that when potassium permanganate is treated with hydrochloric acid, various substances and chlorine result. From the conventions which we use in writing formulæ, since the equation is properly balanced, it also implies the statement that from 2 gram molecular weights of the permanganate (316.1 g.), 5 gram molecular weights of chlorine (354.6 g.) can be obtained.

Knowing this, we can determine just what weight of permanganate we should have to start with to produce any desired weight of chlorine, or vice versa, and from corresponding relationships, also expressed by the equation, the weight of acid necessary, and the weights of the final products produced. The computation of these things comes under the type of problem called *calculation of weights from equations.*

Suppose that we desired to prepare 10 g. of chlorine.

Let x = weight of $KMnO_4$ required.

Then obviously, $316.1 : 354.6 = x : 10$

or
$$x = \frac{316.1 \times 10}{354.6} = 8.91 \text{ g.}$$

This type of problem is better solved systematically as follows:

$$\underset{\frac{2\times158.06}{x}}{2KMnO_4} + 16HCl \rightleftharpoons 2KCl + 2MnCl_2 + 8H_2O + \uparrow \underset{\frac{5\times70.92}{10}}{5Cl_2}$$

Rewriting,
$$\frac{2\times158.06}{x} = \frac{5\times70.92}{10}$$

Solving,
$$x = \frac{3161}{354.6} = 8.91 \text{ g.}$$

Method. (1) *Write and properly balance the equation for the required reaction.*

(2) *Under the formulae of the substances in the equation with which the problem deals, write the weights represented by the equation, and directly beneath these the weights given in the problem, representing the unknown one by an appropriate letter.*

(3) *From these write the proportion in the order in which the numbers appear.*

(4) *Solve for the unknown quantity.*

A somewhat more complicated variation of the same problem is frequently met with where a series of chemical reactions is involved.

Example. What weight of magnesium would be required to produce 100 g. of nitric acid by the following process?

$$3Mg + N_2 \rightleftharpoons Mg_3N_2$$

$$Mg_3N_2 + 6H_2O \rightleftharpoons 2NH_3 + 3Mg(OH)_2$$

$$NH_3 + 2O_2 \rightleftharpoons HNO_3 + H_2O$$

It is evident that this problem could be solved by applying the rule just given successively to each equation, finding the weight of ammonia required to produce 100 g. of nitric acid, the weight of magnesium nitride necessary to form that weight of ammonia, and finally the weight of magnesium essential to produce that weight of magnesium nitride, which would be the weight required.

A much shorter and simpler method, once it is understood, is to make the original equations consecutive and then to perform all of the calculations in one step. This consists in fixing the attention upon the substances in each reaction which are required to obtain the final substance from the original. These substances are always obvious as they are the ones which are common to successive reactions. Then multiply each equation through by a number which will make the expressed quantity of each of these substances the same in successive reactions. In this case multiply the third equation, only, by 2 throughout. We have, then,

$$3Mg + N_2 \rightleftharpoons Mg_3N_2$$

$$Mg_3N_2 + 6H_2O \rightleftharpoons 2NH_3 + 3Mg(OH)_2$$

$$2NH_3 + 4O_2 \rightleftharpoons 2HNO_3 + 2H_2O$$

Hence 3Mg produces successively Mg_3N_2, $2NH_3$, and finally $2HNO_3$.

Or, $$3Mg \rightarrow 2HNO_3$$

$$\frac{3 \times 24.32}{x} = \frac{2 \times 63.016}{100}$$

Hence, $$\frac{72.96}{x} = \frac{126.03}{100}$$

Solving, $$x = \frac{7296}{126.03} = 57.91 \text{ g.}$$

After the equations are consecutive, the manner of solution is the same as in the first type, and is therefore accomplished just as easily and in what amounts to one step, as the problem of making the equations consecutive is really a mental one.

Alternative Method.* Problems of this type may also be solved by the "molar" method.

In the first case considered we observed the fact that 2 moles of $KMnO_4$ produce 5 moles of Cl_2, or $\frac{2}{5}$ mole yield 1 mole of Cl_2.

10 grams of Cl_2 are $\frac{10}{70.92}$ moles of the substance.

Since $\frac{2}{5}$ mole of $KMnO_4$ produce 1 mole of Cl_2, to produce $\frac{10}{70.92}$ moles will require $\frac{2}{5}\times\frac{10}{70.92}$ moles of $KMnO_4$.

One mole of $KMnO_4$ is 158.05 g.

Hence, $\frac{2}{5}\times\frac{10}{70.92}$ moles $=\frac{2}{5}\times\frac{10}{70.92}\times 158.05$ g. $=8.91$ g.

Therefore 8.91 grams of chlorine will be produced.

In problems of the second type this method is applicable after the equations have been made consecutive.

Refer to this when you reach Chapter VIII and attempt to devise a similar method for calculating volumes from equations.

PROBLEMS

1. How many grams of pure hydrogen peroxide will convert 10 g. of lead sulphide into lead sulphate ($PbSO_4$)?

2. 2.4 g. of zinc were treated with an excess of dilute sulphuric acid. Calculate the weight of each product formed.

3. Sodium chloride and sulphuric acid react to give hydrogen

---

* This method is analogous to that used later in Analytical Calculations (q. v.).

chloride and sodium sulphate. How much salt would be consumed in the preparation of 20 lbs. of sodium sulphate?

4. How many grams of manganese dioxide are needed to give, when decomposed by heat, 12 g. of oxygen? How much manganous-manganic oxide (Mn_3O_4) will be formed?

5. How many grams of tin may be obtained from 100 Kg. of a tin ore containing 3% of SnO_2, assuming that 5% of the tin is lost during extraction?

6. How many kilograms of potassium nitrate can be made from a metric ton of sodium nitrate? How many kilograms of potassium chloride must be used? (A metric ton is 1000 Kg.)

7. Fifty kilograms of impure stibnite containing 60% of Sb_2S_3 are heated with iron. How many kilograms of antimony are obtained?

8. Find how many grams of potassium chloride and sulphuric acid are needed to produce 2.8 g. of hydrogen chloride.

9. Calculate the weight of manganese dioxide and of hydrochloric acid necessary to produce 4.8 g. of chlorine. How many grams of manganese chloride were formed?

10. What weight of iron could be made, theoretically, from 200 tons of an ore containing 80% of ferric oxide, Fe_2O_3?

11. Calculate the weight of barium chloride which, reacting with sufficient sulphuric acid, will yield 1.46 g. of barium sulphate.

12. What weight of mercuric oxide would yield 25 g. of oxygen, and how much mercury would be produced at the same time?

13. How much potassium chlorate ($KClO_3$) would yield as much oxygen as 250 g. of mercuric oxide?

14. How much zinc must be dissolved in dilute sulphuric acid to produce 40 lbs. of crystallized zinc sulphate, $ZnSO_4,7H_2O$?

15. Calculate the weight of sodium hydroxide that would be formed by the action of 5 g. of sodium on water. What weight of hydrogen would be liberated?

16. A solution of sodium bromide is treated with an excess of silver nitrate ($AgNO_3$) and 0.65 g. of silver bromide are precipitated. What weight of sodium bromide was contained in the original solution?

17. 1.4 g. of an alloy of copper and silver were dissolved in nitric acid and hydrochloric acid was added. The silver chloride precipitated weighed 1.6 g. What was the percentage composition of the alloy?

18. Thirty kilograms of a phosphate rock which contained 58% of tricalcium phosphate, $Ca_3(PO_4)_2$, are heated in an electric furnace with sand and coke. How many grams of phosphorus are produced?

19. Equal weights being taken, which will neutralize the larger quantity of acid: sodium hydroxide or potassium hydroxide; sodium carbonate or sodium bicarbonate?

20. What weight of hydrogen chloride would be necessary for the complete neutralization of 2.63 g. of sodium hydroxide?

21. What weight of iodine could be obtained from 150 g. of potassium iodide? How much sulphuric acid would be needed, assuming that the acid sulphate of potassium, $KHSO_4$, is produced?

22. Calculate the weight of potassium chlorate that will produce, when heated, 74.5 g. of potassium chloride. What weight of oxygen would be formed at the same time?

23. Calculate how many grams of silver sulphate and of copper sulphate you could make from a dime which is 10% copper. (A dime weighs 2.48 g.)

✓ 24. How many grams of hydrogen can be obtained by the reaction of 10 grams of magnesium with dilute sulphuric acid? How much magnesium sulphate? How much acid is necessary?

✓ 25. How many grams of manganese dioxide are required to give, with an excess of hydrochloric acid, 10 grams of chlorine?

26. How many pounds of pure calcium cyanamide, $CaCN_2$, are necessary to produce 40 lbs. of ammonia?

27. What weight of ammonium sulphide is present in a solution which will just dissolve 0.65 g. of stannic sulphide, SnS_2?

28. Suppose that a glass had the formula $Na_2O,CaO,6SiO_2$. How much sodium carbonate and limestone would be necessary to make 250 lbs. of it?

29. What weight of sodium thiosulphate, $Na_2S_2O_3$, will react with 0.318 g. of iodine?

30. What weights of potassium hydroxide, sodium hydroxide and barium hydroxide, respectively, will neutralize 5 g. of sulphuric acid?

31. What weight of sodium chloride will precipitate all of the silver from a solution made by dissolving 1 g. of silver in nitric acid?

32. What weight of oxygen gas could be obtained by the complete decomposition of 100 g. of pure potassium chlorate? If the chlorate used contained 10% of its weight of potassium chloride, what would be the difference in the amount of oxygen obtained?

33. 310 g. of borax crystals ($Na_2B_4O_7,10H_2O$) are dissolved in a small quantity of water and sulphuric acid is added. How many grams of sulphuric acid should be used and how many grams of boric acid (H_3BO_3) will be obtained?

34. How much silver chloride may be formed by burning 54 g. of silver in chlorine gas?

35. How much sulphuric acid was there in a solution from which an excess of barium chloride precipitated 2.836 g. of barium sulphate? If the sulphuric acid was obtained by the oxidation of the sulphur in 4 g. of a sulphur ore, calculate the per cent of sulphur in the ore.

36. How many grams each of carbon, sulphur, and phosphorus could be completely burned in the oxygen evolved by heating 122.5 g. of potassium chlorate?

37. What weight of manganese dioxide is necessary to produce 100 g. of chlorine by the action of sulphuric acid on sodium chloride?

38. What weight of sulphuric acid containing 20% water can be made from 5 tons of iron pyrites which contains 44% sulphur?

39. Five grams of copper were dissolved in nitric acid and the resulting solution was treated with hydrogen sulphide. What weight of copper sulphide was precipitated?

40. What weight of aluminium is necessary to produce one kilogram of nitric acid by the following series of reactions:

$$2Al + N_2 \rightleftharpoons 2AlN$$

$$AlN + 3H_2O \rightleftharpoons Al(OH)_3 + \uparrow NH_3$$

$$NH_3 + 2O_2 \rightleftharpoons HNO_3 + H_2O$$

41. During the recent war Professor J. C. Bucher developed a process for the fixation of atmospheric nitrogen which depended upon the reaction: $Na_2CO_3 + 4C + N_2 \rightleftharpoons 2NaCN + \uparrow 3CO$. What weight of sodium carbonate is necessary to "fix" 100 g. of nitrogen? What weight of sodium cyanide will be produced?

42. What weight of potassium permanganate ($KMnO_4$) may be reduced by the hydrogen peroxide which can be made from 3.5 g. of barium peroxide?

43. Five grams of copper are dissolved in concentrated sulphuric acid and the sulphur dioxide which is evolved is passed into a solution of potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid. What weight of the dichromate will be reduced?

44. What weight of stannous chloride ($SnCl_2$) is necessary to precipitate the mercury in 5 g. of mercuric chloride ($HgCl_2$)?

45. Ten grams of zinc are dissolved in excess hydrochloric acid, and the hydrogen which is generated is passed over hot cupric oxide. What weight of water is produced?

46. What weight of potassium dichromate must be heated with hydrochloric acid in order to evolve sufficient chlorine to liberate the iodine from 1.656 g. of potassium iodide?

47. 0.352 g. of a sample of pyrolusite were heated with hydrochloric acid and the chlorine which was evolved was passed into a solution of potassium iodide from which it liberated 0.864 g. of iodine. Find the percentage of manganese dioxide in the original pyrolusite.

48. Ten grams of an alloy of copper were dissolved in nitric acid and hydrogen sulphide was passed into the resulting solution, precipitating 7.5 g. of copper sulphide. What was the per cent of copper in the alloy?

49. If 50 g. of pure ferrous sulphide are burned to form sulphur dioxide which is then passed through acid potassium perman-

ganate solution, what weight of manganous chloride ($MnCl_2$) will be formed?

50. A solution containing potassium chloride, potassium bromide, and potassium iodide is precipitated with silver nitrate, and the precipitate of silver chloride, silver bromide, and silver iodide weighs 10.97 g. The precipitate is then heated with bromine water, which converts the silver iodide to silver bromide, and the precipitate then weighs 9.91 g. It is then heated with chlorine water in order to convert it all into silver chloride which then weighs 8.24 g. Find the quantities of potassium chloride, potassium bromide, and potassium iodide in the original mixture.

51. What weight of phosphorus can be burned in the nitrous oxide obtained by heating 10 g. of ammonium nitrate?

52. One gram of potassium chlorate is treated with hydrochloric acid and the liberated chlorine is passed into a solution of potassium iodide. If sodium thiosulphate is then added to the free iodine, what weight of sodium thionate ($Na_2S_4O_6$) will be formed?

53. Five grams of ferrous sulphide are burned to form sulphur dioxide which is passed into water. The resulting sulphurous acid is oxidized to sulphuric acid by means of iodine and then precipitated by means of barium chloride. What weight of barium sulphate is formed?

54. One gram of arsenious chloride ($AsCl_3$) is placed in a hydrogen generator and reduced to arsine (AsH_3) which is then burned to form arsenious oxide (As_2O_3). If the oxide is dissolved in water and precipitated by copper sulphate, what weight of Scheele's Green ($CuHAsO_3$) will be formed?

55. What weight of copper must be dissolved in dilute nitric acid in order to evolve a sufficient quantity of nitric oxide to prepare 5 g. of ferrous nitrosyl sulphate [$Fe(NO)SO_4$] when passed through a ferrous solution?

56. What weight of nitric acid is required to prepare a sufficient quantity of aqua regia to dissolve 1.54 g. of gold?

57. What weight of sodium carbonate can be made from 100 g. of sulphuric acid in the first of the following series of reactions:

$$NaCl+H_2SO_4 \rightleftharpoons NaHSO_4+\uparrow HCl$$
$$NaHSO_4+NaCl \rightleftharpoons \uparrow HCl+Na_2SO_4$$
$$Na_2SO_4+4C \rightleftharpoons Na_2S+\uparrow 4CO$$
$$Na_2S+CaCO_3 \rightleftharpoons Na_2CO_3+CaS$$

58. 1.5 g. of copper sulphate are treated with excess of potassium iodide and the liberated iodine is allowed to react with sodium thiosulphate. What weight of sodium thionate ($Na_2S_4O_6$) will be formed?

59. Ten grams of sodium sulphite are heated strongly and the resulting solid is treated with hydrochloric acid. What weight of lead sulphide can be produced by passing the hydrogen sulphide which is generated through a solution of lead nitrate?

60. Red phosphorus is treated with iodine and the product is hydrolyzed by means of water. What weight of phosphorus is required to produce 4.5 g. of pure hydrogen iodide by this method?

61. 1.5 g. of lead are dissolved in nitric acid and the solution is treated with hydrochloric acid. The precipitated lead chloride is filtered off and weighed. 1.8 g. of the chloride were obtained. What was the percentage purity of the lead?

62. Coin silver is 90% pure. What weight of sodium thiosulphate, when dissolved in water, will just dissolve the chloride of silver obtained from 2 g. of coin silver?

63. A solution of ferric chloride which contains 3.45 g. of the solute is acidified with hydrochloric acid. What weight of zinc must now be added to reduce the iron to the ferrous condition?

64. Five grams of iron are dissolved in hydrochloric acid. Nitric acid is then added to oxidize the iron to the ferric state, ammonia water is used to completely precipitate the iron as the hydroxide, and the latter is then filtered off. What weight of ferric oxide will be obtained upon heating?

65. What weight of manganese dioxide will liberate enough chlorine from hydrochloric acid to displace 2.55 g. of iodine from potassium iodide? If the manganese dioxide is 87% pure, what weight will be needed?

CHAPTER VI

VOLUMES OF GASES

Unlike the volume of a given weight of a liquid or solid, the volume of a given weight of gas may vary considerably according to circumstances. In the former cases quite careful measurements are required to discover any variation at all, while in the latter even fairly rough experimentation reveals rather large differences. The factors which may affect the volumes of gases, weight remaining constant, are pressure and temperature.

The effects of changes in temperature and pressure upon the volume of a gas are generally stated as:

Boyle's Law. The temperature remaining constant, the volume *of a given weight of any gas* varies inversely as the pressure.

Charles' Law. The pressure remaining constant, the volume *of a given weight of any gas* varies *directly* as the absolute temperature.

With the aid of these two laws, if the volume of a constant weight of any gas is known at any temperature and pressure, we can calculate:

(*a*) The volume at any other temperature and pressure.

(*b*) The temperature at which it will occupy any given volume at any pressure.

(*c*) The pressure at which it will occupy any given volume at any temperature.

For many purposes it is desirable to know the volumes of gases at 0° C. and 760 mm. pressure (=one atmosphere) when the volumes under other conditions are known.

This set of conditions is so important that it is usually termed *Normal* or *Standard Temperature* and *Pressure,* abbreviated N.T.P. or S.T.P.

These laws may be applied to the solution of problems in two general ways:

I. We may restate the above laws mathematically:

$$v \propto \frac{1}{p} \quad (\propto \text{ means } \textit{varies as}) \quad . \quad . \quad . \quad . \quad (1)$$

$$v \propto T \quad (T = \text{absolute temperature}) \quad . \quad . \quad (2)$$

From which, $$v \propto \frac{T}{p} \qquad \text{(Why?)}$$

or, $$v = \frac{kT}{p}$$

and, $$\frac{vp}{T} = k \qquad (k \text{ is a constant})$$

Suppose that a weight of gas occupies a volume of v_1 cubic centimeters at $T_1°$ absolute and p_1 millimeters pressure.

Then, $$\frac{v_1p_1}{T_1} = k$$

If the temperature now changes to $T_2°$ absolute and the pressure to p_2 millimeters, the weight of the gas being the same, its volume will now be some other value v_2.

But $\frac{v_2p_2}{T_2} = k$ is still true, k being the same.

Hence $$\frac{v_1p_1}{T_1} = \frac{v_2p_2}{T_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In this formula it is obvious that, knowing any five terms it is possible to calculate the sixth.

Example. What volume will 500 cc. of air at 25° C. and 770 mm. pressure occupy at N.T.P.?

Here we have

$$v_1=500 \text{ cc.};\ p_1=770 \text{ mm.};\ T_1=(25+273)°;$$
$$v_2=x \text{ cc.};\quad p_2=760 \text{ mm.};\ T_2=(0+273)°.$$

Substituting in (3), $$\frac{500\times 770}{298}=\frac{760x}{273}$$

Solving, $$x=\frac{273\times 500\times 770}{298\times 760}=464.1 \text{ cc.} \quad . \ . \ . \ . \quad (4)$$

II. To solve a problem by Method I we must remember formula (3). Knowing the laws previously stated, it is, however, possible to reason out the problem and thereby obtain the answer without direct reference to the formula. Let us solve the same problem.

We know that the required volume will be some fraction of the original one. The factors which tend to change the original volume are temperature and pressure, and, as a factor is something which multiplies, we may write:

$$x=\frac{T}{}\times\frac{p}{}\times 500\text{cc.}$$

Now consider the temperature. Originally it was 25° C. or 298° A.,* finally it became 0° C. or 273° A. The temperature diminishes in going from the original to the final conditions. Hence, by Charles' Law, the volume due to this factor will diminish in the same proportion. We can then write these numbers into our expression placing the larger in the denominator to make the fraction less than 1 and so diminish the volume. We now have:

$$x=\frac{273}{298}\times\frac{p}{}\times 500 \text{ cc.}$$

Consider the pressure. Originally it was 770 mm.; finally, 760 mm. By Boyle's Law, since the pressure diminishes, the effect will be to increase the volume in the inverse ratio. Hence the larger number must go in the numerator of the fraction.

---

* Also abbreviated 298° K.

Therefore

$$x=\frac{273}{298}\times\frac{770}{760}\times 500 \text{ cc.}=464.1 \text{ cc.}$$

which, of course, is the same answer as before.

This method, like any common sense one, is preferable to another which depends solely upon the mechanical remembrance of a formula.

Practical Corrections and Possibilities of Errors.

1. *Units.* All temperatures must be converted to **absolute.** All units must be the same throughout; i.e., pressure may be expressed in millimeters of mercury, centimeters of mercury, atmospheres, pounds per square inch, etc. These may be employed in either method without conversion, *but* both p_1 and p_2 must be in the same units, as millimeters or pounds per square inch. The same precaution must be observed for volumes.

2. *Pressure.* In the laboratory a gas is usually collected over a liquid in the pneumatic trough, possibly in a eudiometer tube, as shown in Fig. 3. In such cases the gas may be considered to be confined at barometric pressure only if the exterior and interior liquid levels are the same.

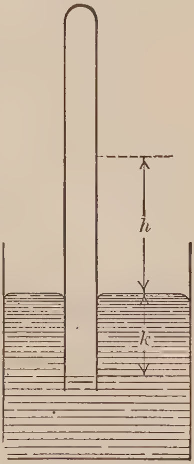

FIG. 3.

If the liquid is mercury, and the level inside is above that outside the tube, the gas is confined at less than atmospheric pressure and the difference in level h, in millimeters, must be *subtracted* from the barometric pressure in millimeters (Fig. 3). If the level inside is below that outside, as at k, then k in millimeters must be *added* to the barometric pressure in millimeters.

If the liquid is other than mercury, the difference in levels must be multiplied by the specific gravity of the liquid and divided by that of mercury, and the result added to or subtracted from the barometric pressure as determined by the considerations in the preceding paragraph. The specific gravity of water may be taken as 1 and that of mercury as 13.6.

3. *Vapor Pressure Correction.* When a gas is collected over a liquid it is saturated with the vapor of that liquid at the given temperature. The measured volume of gas is greater by the volume of the liquid vapor, or the pressure actually exerted by the gas in question is that determined in section 2 above minus that exerted by the vapor of the liquid.*

This correction is small and is usually neglected if the liquid is mercury. If the liquid is water, it is appreciable, and varies with the temperature.

The values for the vapor tension of water at different temperatures will be found in the Appendix, page 134. The pressure exerted by the mixture of gases is obtained by the method of the preceding section, the vapor pressure of water at the given temperature is found from the table, and subtracted from it (see that the units are the same) and the resulting pressure is taken as that actually exerted by the gas.

For liquids other than water and mercury other tables would be required.

Example 1. 100 cc. of gas are confined over water in a eudiometer tube at 25° C. and 750 mm. pressure. What would be the volume of the dry gas *at the same temperature and pressure?* The water levels are the same.

---

* Cf. the *Law of Partial Pressures* in any standard textbook.

From the Appendix, the vapor tension of water at 25° C. is 23.5 mm.

Hence the gas is actually confined at a pressure of $750-23.5=726.5$ mm.

The volume of dry gas is, therefore,

$$\frac{726.5}{750}\times\left(\frac{298}{298}\right)\times 100 = 96.9 \text{ cc.}$$

What would be the volume of the moist gas if confined over mercury under the same conditions?

Example 2. If 1250 cc. of nitrogen at +37° C. stand in a eudiometer tube over mercury, the level within the tube being 20 mm. below that without and the barometric pressure being 747 mm., what would be the volume of the gas under standard conditions?

Original conditions: $v=1250$ cc.; $T=273+37=310°$ K.; $p=747+20=767$ mm.

Final conditions: $v=x$; $T=0+273=273°$ K.; $p=760$ mm.

Hence, $x=\frac{273}{310}\times\frac{767}{760}\times 1250=1013$ cc.

PROBLEMS

1. Ninety cubic centimeters of air at 20° C. become 150 cc. when heated. What is the new temperature?

2. A certain volume of gas measures 100 cc. at a pressure of 400 mm. By changing the pressure, the volume becomes 85 cc. What is the second pressure?

3. To what temperature must a given volume of gas at Normal Temperature and Pressure be heated in order to increase its volume by 50%?

4. A given volume of gas is confined at N.T.P. To what pressure must it be subjected in order that its volume shall be one-half? In order that its volume shall be 50% greater?

5. A container is filled with carbon dioxide at four atmospheres pressure and 20° C. If the container can stand safely a pressure of only 90 lbs. per square inch, to what temperature must the gas be brought before the container will break?

6. Given 100 liters of a gas at N.T.P., how many gas holders

of 5 liters each can be filled at four atmospheres pressure and 0° C. with this volume of gas?

7. Ten liters of steam at 100° C. and one atmosphere pressure would occupy what volume at 150°C.?

8. Ten liters of steam at 100° C. and one atmosphere pressure would exert what pressure at 150° C. if the volume remained the same?

9. A quantity of hydrogen measures 53 cc. at a temperature of 20° C. What would it measure at 28° C.?

10. 80.2 cc. of air are confined in a tube over mercury when the barometer stands at 768 mm.; the next day the barometer reads 758 mm. What volume would the air then have?

11. 151 cc. of nitrogen stand in a tube over mercury with the inside level 139 mm. above the outside level. What volume would the gas have if the levels were the same? The barometer reads 754 mm.

12. 200 cc. of a gas are confined in a tube over mercury, the inside level being 120 mm. below the outside level. If the pressure (barometric) at the time is 749 mm., what volume would the gas occupy if the levels were equalized?

13. If a quantity of nitrogen under 900 mm. pressure and 20° C. occupies 300 cc., what volume will it occupy at 100° C. under a pressure of 600 mm.?

14. Given 1 liter of gas at 40° C. and 760 mm. pressure, what volume will it occupy at 90° C. and four atmospheres pressure?

15. Given 200 cc. of oxygen at 10° C. and 756 mm. pressure, find the volume at 0° C. and 760 mm. pressure.

16. A sealed bottle, which can stand an internal pressure of four atmospheres, is filled with gas at 16° C. and 760 mm. pressure. Above what temperature would it be liable to burst?

17. Reduce 300 cc. of gas at 35° C. and 740 mm. pressure to N.T.P.

18. Find the volume at N.T.P. of 150 cc. of hydrogen at 20° C. and 768 mm. pressure.

19. A balloon holds 10,000 cu. ft. of gas when filled at 20° C. and 765 mm. pressure. What will be the volume of the balloon if the temperature falls to −30° C. and the pressure to 700 mm.?

20. Ten grams of a certain gas occupy 10 liters at N.T.P. What will be the weight of the same volume of gas at 30° C. and five atmospheres pressure?

21. 100 cc. of gas are confined over water in a eudiometer tube at 25° C. and 750 mm. pressure. What would be the volume of the dry gas at the same temperature and pressure? The water levels are the same.

22. 112 cc. of hydrogen are confined in a tube over water at 20° C. If the inner and outer levels are the same, what volume would the dry gas occupy at the same temperature? The pressure is 762 mm.

23. Given 162.5 cc. of gas confined over water at 23° C. and 753 mm. Correct for the vapor tension of water and reduce the volume to N.T.P.

24. A tube containing potassium chlorate was heated and the oxygen which was formed was collected over water. The volume was 450 cc. at 40° C. and 720 mm. pressure.

- (*a*) What would be the volume under the same conditions over mercury?
- (*b*) What would be the volume of the dry gas at N.T.P.?
- (*c*) If the heated tube lost 0.49 g. in weight, calculate the weight of a liter of dry oxygen at N.T.P.

25. Reduce 189 cc. of gas over water at 15° C. and 750 mm. to N.T.P., making the aqueous tension correction.

26. Reduce 110 cc. of gas at 5° C. and 747 mm to 0° C. and 760 mm.

27. Convert 500 cc. of gas at 25° C. and 700 mm. to 18° C. and 745 mm.

28. Reduce 250 cc. of gas standing over water at 22° C. and 755 mm. to the dry condition at N.T.P.

29. If 25 liters of gas at standard conditions are cooled to −10° C. and the pressure is reduced to 723 mm., what will be the new volume?

30. 310 cc. of hydrogen at 10° C. and 730 mm. pressure will occupy what volume at 187° C. and 590 mm. pressure?

31. 1704 cc. of nitrogen at 11° C. and 760 mm. pressure are brought to a temperature of 27° C. and a pressure of 900 mm. What is the new volume?

32. If 2 liters of gas are confined at a temperature of 25° C. and a pressure of 790 mm., to what temperature must the gas be brought in order to occupy a volume of 3 liters at a pressure of three atmospheres?

33. Given 291 cc. of gas at a temperature of 21° C. and 712 mm. pressure. At what temperature will the volume be 271 cc. at a pressure of 740 mm.?

34. If 300 cc. of gas exert a pressure of 600 mm. at a temperature of 20° C., what pressure will the gas exert if confined in the same volume at 300° C.?

35. Given 50 liters of gas at N.T.P., what pressure will be necessary to put this volume of gas into a gas holder the volume of which is 10 liters at 20° C.?

36. What pressure will 1 liter of gas at N.T.P. exert when confined to a volume of 5 cc. at 600° C.?

37. 271 cc. of hydrogen at 269° C. and 900 mm. are cooled to $-51°$ C. and the pressure is reduced to 666 mm. Calculate the final volume.

38. 112.1 cc. of nitrogen, saturated with water vapor at 16° C. and 744 mm. pressure, will occupy what volume, when dry, under standard conditions.?

39. A gas holder contains 10 liters of air confined over water at 20° C. and 756 mm. What will the gas measure when dried, the conditions remaining the same?

40. If 251 cc. of helium are confined over water at 23° C. and 760 mm. pressure, what volume would the gas occupy when confined over water at 40° C. and 740 mm. pressure?

41. Change 123 cc. of gas saturated with water vapor at 21° C. and 762 mm. pressure to the dry condition at N.T.P.

42. What would be the volume, when confined over water, of 250 cc. of dry gas at N.T.P.? At 30° C. and 750 mm.?

43. A cubic foot of gas at N.T.P. would occupy what volume at 20° C. and 740 mm. pressure?

44. Five grams of a gas at 23° C. and 752 mm. pressure, confined over water, occupy 4.970 liters. Calculate the weight per liter of the gas at standard conditions.

45. A test tube with a cross-sectional area of 1 sq. cm. and

15 cm. in length is filled with air at 20° C. and 740 mm. pressure. If the test tube is immersed mouth downward, in a bowl of mercury so that the mouth is 10 cm. below the surface of the mercury, how far will the mercury rise in the tube?

46. In the preceding problem, if the liquid were water, how far would the mouth of the tube have to be immersed before the water would rise in the test tube to the same extent?

47. How far will water rise in a diving bell when it is immersed to a depth of 50 ft.? Assume the temperature to remain the same. The diving bell is 15 ft. high.

48. 342 cc. of dry hydrogen at N.T.P. will occupy what volume when confined over water at 23° C. and 740 mm. pressure?

49. Given 132 cc. of air confined over water at 30° C. and 762 mm. pressure. What per cent of this volume is water vapor?

50. Reduce 78.5 cc. of hydrogen confined over water at 23° C. and 759 mm. pressure to the dry condition at N.T.P.

51. In order to find the per cent of oxygen in air, the oxygen is absorbed by means of phosphorus and the following data are obtained:

	Original	*Final*
Volume............	99.8 cc.	77.0 cc.
Temperature........	24° C.	19° C.
Pressure...........	763 mm.	750 mm.

The air stands over water and the levels are adjusted in reading both volumes. Determine the per cent of oxygen.

52. A quantity of hydrogen occupies 500 cc. in a tube over mercury. The level within the tube is 70 mm. above that without, the temperature is 40° C., and the barometric pressure is 740 mm. What volume would it occupy at N.T.P.?

53. A liter of oxygen is forced into a vessel containing a liter of nitrogen, each gas being individually under a pressure of 760 mm. What is the resulting pressure ?

54. A certain quantity of gas has a volume of 15 liters at 740 mm. On coordinate paper plot a curve showing the application of Boyle's Law when the pressure is changed to 150 mm., 200 mm., 250 mm., 300 mm., and 500 mm.

55. 151 cc. of gas are confined in a eudiometer tube over mercury, the level within being 49 mm. above that without. The temperature is 23° C. and the barometric pressure is 762 mm. What will be the volume indicated if the tube is adjusted so that the inner level is 52 mm. below that without and the temperature meanwhile becomes 28° C., the pressure remaining the same?

56. A volume of gas in a eudiometer tube over water measures 75.5 cc. at 25° and 765 mm. pressure, but the level of the water in the tube is 95 mm. above that without. What will be the volume of the dry gas at N.T.P.?

57. To what pressure must 500 cc. of gas confined over water at 25° C. and 755 mm. pressure be subjected, when dry, to cause it to occupy a volume of 100 cc. at 50° C.?

58. A given volume of gas in a eudiometer tube over water at 25° C. and 761 mm. pressure is actually exerting what pressure, if the inner level of water is 71 mm. below the outer level?

59. Given 15 cc. of gas over water at 23° C. and 757 mm. pressure. What volume will the gas occupy over mercury under the same conditions if the water vapor is removed?

60. What volume will 45 cc. of dry nitrogen at N.T.P. occupy when confined in a eudiometer tube at 25° C. and 778 mm. pressure over water?

61. Sixty-five cubic centimeters of air over water at 31° C. and 728 mm. pressure will occupy what volume over water at N.T.P.? Over mercury? Dry, over mercury?

62. Seventy-five cubic centimeters of nitrogen are confined in a eudiometer tube over water at 24° C. and 765 mm. pressure. The inner level is 25 mm. above that without. What volume will the gas occupy, when dry, over mercury at 30° C. and 745 mm. pressure, if the inner level is 11 mm. below that without?

63. Eighty-seven cubic centimeters of oxygen are confined in a tube over water at 24° C. and 768 mm. pressure. The inner water level is 35 mm. above that without. How far must the tube be pushed down into the water in order to make the volume indicated by the inner water level 84 cc.?

CHAPTER VII

WEIGHTS OF GASES

In the case of solids and liquids it is frequently desirable to know the numerical value of the density or specific gravity in order to compute the volume which a given weight of material will occupy. When this information is desired, we have two courses open to us; to determine the specific gravity or density experimentally, or to consult a table of these quantities prepared by someone else.

Because of the regularity in the behavior of gases, it is easy to calculate the corresponding quantities if we are familiar with chemical theory, and if the chemical formula of the gas is known. Because of the striking similarity in the response of all gases to changes in conditions, Avogadro was led to the conclusion, formerly an hypothesis, but now known to be approximately true, that:

In equal volumes of all gases, at the same temperature and pressure, there is the same number of molecules.

There are three values in the case of gases which correspond to density and specific gravity of liquids and solids (chosen because the same values, while just as easily computed, are neither as useful, nor as easily manipulated, because of their small size): **density, specific gravity,** and **vapor density,** the latter usually abbreviated V.D. These values vary much more widely than the similar ones for liquids and solids as the temperature and pressure change, but from the formula of any gas all may be calculated by reference to Avogadro's Hypothesis.

Definitions. The **density** of a gas is the weight of 1 liter of that gas at any temperature and pressure. (The weight of a liter is taken rather than that of a cubic centimeter because the latter would be inconveniently small.)

The **specific gravity** of a gas is the weight of a given volume of that gas at any temperature and pressure compared to the weight of the same volume of air at Normal Temperature and Pressure.

The **vapor density** of a gas is the weight of a given volume of that gas at any temperature and pressure compared to the weight of the same volume of hydrogen at Normal Temperature and Pressure.

It will be seen that these quantities are most easily computed at Normal Temperature and Pressure. These values should always be obtained first, after which others, at any conditions, may be obtained from them.

Consider two equal volumes of different gases, A and B, under the same conditions of temperature and pressure (Fig. 4). Let the actual weights of the two volumes be w and w' grams respectively. By Avogadro's Hypothesis, if the number of molecules in volume A is n then that in volume B is also n. Finally, let M be the actual weight in grams of a single molecule of gas A, and M' that of a single molecule of gas B, which is different, since the gases are different, then

$$w = nM$$

and $$w' = nM'$$

or $$\frac{w}{w'} = \frac{nM}{nM'}$$

hence $$\frac{w}{w'} = \frac{M}{M'}$$

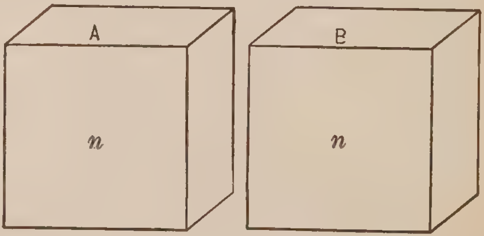

Fig. 4.

This conclusion may be stated as follows: *Under the* *same conditions of temperature and pressure the weights of equal volumes of different gases are proportional to their true molecular weights.*

Since w and w' are quantities which can be determined experimentally by the simple process of weighing, it is obvious that if we knew the molecular weight of any one gas we could then determine those of all others by comparison.

Just as in the case of atomic weights, we make an assumption at this point. We have already assumed that the atomic weight of oxygen is 16. If we assume that oxygen is diatomic (for which there is good reason on wholly unrelated grounds) i.e., contains two atoms in the molecule, then its molecular weight will be 32.

The volume occupied by 32 g. of oxygen at Normal Temperature and Pressure is 22.4 liters. This volume is known as the *Gram-Molecular Volume* because, from what has gone before, it is evident that the weight of any gas which at N.T.P. occupies this volume is the gram-molecular weight of that gas. Or, conversely, the gram-molecular weight of a gas at N.T.P. occupies 22.4 liters, a fact which is more important for the purposes of this chapter.

It is sometimes convenient to recall that the molecular weight in milligrams of a gas at N.T.P. occupies 22.4 cc. (How?) Therefore, the *density of any gas at N.T.P. is the molecular weight divided by* 22.4. Since the molecular weight of hydrogen is 2.016, and this weight at N.T.P. occupies 22.4 liters, the *vapor density of any gas at N.T.P. is its molecular weight divided by* 2.016; or, roughly, **the molecular weight is twice the vapor density.**

Air is a mixture, but, on the average, 22.4 liters at N.T.P., everywhere in the world, weigh about 28.9 g., a value that should be remembered. *The specific gravity of a gas at N.T.P. is therefore its molecular weight divided by* 28.9.

Since we have already found in Chapter VI that the volume of a given weight of gas varies directly as the absolute temperature and inversely as the pressure, it is obvious that the density, vapor density, and specific gravity of gases vary directly as the pressure and inversely as the absolute temperature. Hence, having found these values at N.T.P. they may readily be calculated at any temperature and pressure by methods analogous to those already described in the previous chapter; i.e., either make and remember a formula, or remember the manner of variation.

Example 1. Which of the following gases are heavier than air: ammonia, sulphur dioxide, carbon monoxide, carbon dioxide, oxygen?

Answer. Those whose molar weights are greater than 28.9, i.e., $SO_2 = 64$; $CO_2 = 44$; $O_2 = 32$.

Example 2. Calculate the density and specific gravity of ammonia (NH_3) at 20° C. and 770 mm. pressure.

$$\text{Mol. wt. of } NH_3 = 17.032$$

At N.T.P.

$$\text{density} = \frac{17.032}{22.4} = 0.7601 \text{ g. per liter}$$

$$\text{Sp. gr.} = \frac{17.032}{28.9} = 0.5891$$

*At 20° C**

$$\text{density} = \frac{273}{293} \times \frac{770}{760} \times \frac{17.032}{22.4} = 0.7176 \text{ g. per liter}$$

$$\text{Sp. gr.} = \frac{273}{293} \times \frac{770}{760} \times \frac{17.032}{28.9} = 0.5561$$

*Verify these by reflection.

Example 3. What is the weight of 1 cu. m. of methane at 15° C. and 745 mm. pressure?

(*a*) 1 cu.m. at 15° C. and 745 mm. = 929.4 liters at N.T.P.
(*b*) Methane, CH_4, has a molecular weight of 16.03.
(*c*) 22.4 liters of methane at N.T.P. weigh 16.03 g.
Hence this volume would weigh

$$\frac{929.4}{22.4} \times 16.03 = 669.3 \text{ g.}$$

Graham's Law. *The speed of diffusion of gases varies inversely as the square roots of their densities.*

Example. A liter of nitrogen at N.T.P. weighs 1.25 g. and a liter of hydrogen, 0.089 g. Compare their rates of diffusion.

Hydrogen, being the lighter, diffuses faster than nitrogen in the ratio of $\frac{\sqrt{1.25}}{\sqrt{0.089}}$; i.e., 3.75 times as rapidly.

PROBLEMS

1. What is the density, vapor density, and specific gravity of methane (CH_4) at N.T.P.?

2. What is the density, vapor density, and specific gravity of ethane (C_2H_6) at normal conditions?

3. A liter of bromine gas under standard conditions weighs 7.2 g. What is the molecular weight of bromine?

4. 0.58 g. of acetylene (C_2H_2) have a volume of 495.7 cc. at standard conditions. What is its molecular weight? What is its specific gravity?

5. Calculate the density at N.T.P. of oxygen, ozone, hydrogen chloride, carbon dioxide, and ammonia.

6. What is the weight of 5.5 liters of hydrogen chloride at N.T.P.?

7. How much would the carbon dioxide which would fill a room 10×6×5 m. weigh at N.T.P.?

8. Which of the following gases are lighter and which are heavier than air: oxygen, carbon monoxide, methane, ammonia, sulphur dioxide, hydrogen sulphide?

9. What is the weight of 2 liters of sulphur dioxide at N.T.P.?

10. If 290 cc. of nitrous oxide weigh 0.574 g. at N.T.P., determine the density, specific gravity, and vapor density of the gas.

11. If 0.531 g. of hydrogen iodide occupy 93 cc. at N.T.P., what is the molecular weight of the substance? What is its specific gravity, vapor density, and density?

12. 230 cc. of ether vapor weigh 0.766 g. What is the molecular weight of the substance? What is its specific gravity, density, and vapor density?

13. A gas tank holding 100 liters is filled with hydrogen, the temperature being 38° C. and the pressure 690 mm. How much does the hydrogen weigh?

14. A certain dirigible will hold 500,000 cu. ft. of gas. If the balloon were filled with helium at 20° C. and 760 mm. pressure, how much would the gas weigh?

15. Calculate the relative lifting capacities of two balloons having the same volume if one is filled with hydrogen and the other with helium.

16. What would 21 liters of ammonia at 25° C. and 740 mm. pressure weigh?

17. The largest dirigible when built, the R–38, held 2,724,000 cu. ft. of gas. Calculate its lifting power when filled with hydrogen. When filled with helium.

18. Calculate the density, specific gravity, and vapor density at N.T.P. of chloropicrin, $CCl(NO_2)_3$.

19. What would be the weight of 15 liters of chlorine at 12° C. and 600 mm. pressure?

20. The molecular weight of cyanogen is 52.08. What is its density, specific gravity, and vapor density?

21. What is the weight at N.T.P. of 1 liter of nitrogen; 300 cc. of chlorine; 1500 cc. of ammonia?

22. Find the weight of 5 liters of each of the following gases: hydrogen, nitrogen, oxygen, carbon dioxide.

23. Find the number of liters at N.T.P. occupied by 5 g. of each of the gases in problem 22.

24. The specific gravity of a gas is 6.7. What is its molecular weight? What is its vapor density and density?

25. The vapor of silicon tetrachloride is 5.936 times as heavy as air. What is its vapor density and density?

26. A room is 25 m. long, 15 m. broad, and 10 m. high. What weight of carbon dioxide will it hold at the rate of 4 volumes in 10,000 if the temperature is 20° C. and the pressure 740 mm.?

27. What weight of carbon monoxide will occupy the gram molecular volume at 30° C. and 740 mm. pressure?

28. Determine the density of chlorine at 15° C. and 735 mm. pressure.

29. Calculate the density, vapor density, and specific gravity of hydrogen sulphide at 20° C. and 755 mm. pressure.

30. What is the vapor density, specific gravity, and weight per liter at N.T.P. of phosgene ($COCl_2$)?

31. Determine the density, vapor density, and specific gravity of arsine (AsH_3) at N.T.P.

32. What is the vapor density, density, and specific gravity at N.T.P. of phosphine (PH_3)?

33. How much would a bottle having a volume of 2235 cc. and weighing 45.96 g. in air at 15° C. and 740 mm. pressure weigh when filled with stibine (SbH_3)?

34. What is the density and specific gravity at N.T.P. of nitrosyl chloride ($NOCl$)? At 20° C.?

35. If the molecular weight of oxygen had been taken as 100, what would be the gram molecular volume?

36. If the molecular weight of oxygen had been taken as 100, would the vapor density of a gas be half its molecular weight? Would it have the same numerical value as at present? Why?

37. Determine the density of each of the oxides of nitrogen at N.T.P.

38. What are the values of the specific gravities of the oxides of nitrogen?

39. What should be the weight of 1 liter of ammonium chloride (NH_4Cl), as a gas, at 200° C. and one atmosphere pres-

sure? Would 1 liter of a mixture of ammonia gas and hydrogen chloride weigh the same if they were mixed in equimolecular quantities? Does this suggest a method for determining whether ammonium chloride dissociates or not?

40. What volume would 5 g. of nitrous oxide occupy at 20° C. and 640 mm. pressure?

41. Assuming that the average atmospheric pressure is 15 lbs. per square inch, how many miles thick would the earth's atmosphere be if its density were uniform?

42. Determine the density of chlorine at 25° C. and 750 mm. pressure.

43. A liter of marsh gas at standard conditions weighs 0.72 g. What is the molecular weight of marsh gas? What is its vapor density, specific gravity, and density?

44. What is the vapor density, specific gravity, and density of acetylene (C_2H_2) at N.T.P.?

45. The specific gravity of a certain gas is 3.2. What is its vapor density? What will be the volume occupied by 10 g. of the gas at 20° C. and 752 mm.?

46. The density of a gas at N.T.P. is 5.236 g. per liter. What is its molecular weight? Vapor density? Specific gravity?

47. Calculate the density, specific gravity, and vapor density at N.T.P., of hydrogen, hydrogen bromide, and hydrogen iodide. At 25° C. and 765 mm. pressure.

48. A gas holder can hold 21 g. of oxygen. What weights of nitrogen and of carbon dioxide will it hold?

49. The specific gravity of gallium trichloride was found by Boisbaudran to be 11.9 at 273° C. and that of indium trichloride by Victor Meyer to be 7.87 at the same temperature. What are the molecular weights of the two chlorides?

50. At what temperature will 2 g. of carbon dioxide occupy the volume of the same weight of hydrogen at 20° C. and 750 mm. pressure?

51. What volume will 5 g. of acetylene occupy at 50° C. and 712 mm. pressure?

52. At 30° C. and 755 mm. pressure, what will be the

relative weights of equal volumes of nitrogen and carbon dioxide?

53. What is the density and specific gravity of ethylene (C_2H_4) at 30° C. and 750 mm. pressure?

54. At what pressure, at 50° C., will 5 g. of nitrous oxide occupy the volume which will contain the same weight of ammonia at 20° C. and 300 mm. pressure?

55. If air is approximately 20% oxygen by volume, what weight of oxygen is there in a room $10 \times 5 \times 4$ m. at 24° C. and 764 mm. pressure?

56. On coordinate paper plot the specific gravity of carbon dioxide at 0° C. for the following pressures: 150 mm., 200 mm., 300 mm., 400 mm., 500 mm., and 700 mm.

57. What is the vapor density of steam at 100° C. and one atmosphere pressure?

58. What is the specific gravity and density of water vapor at N.T.P.? At 105° C. and 765 mm.?

59. Calculate the density of ether vapor ($C_4H_{10}O$) at 38° C. and one atmosphere pressure.

60. Under the same conditions of temperature and pressure, what will be the relative weights of equal volumes of methane, ammonia, methylamine (CH_5N), and nitrogen pentoxide?

61. Compare the rates of diffusion at N.T.P. of oxygen and chlorine.

62. A liter of carbon dioxide weighs 1.9768 g. and a liter of nitrogen weighs 1.2507 g. Compare their rates of diffusion accurately.

63. What are the relative rates of diffusion of hydrogen and helium? Is this ratio constant at all temperatures and pressures, or is it the same for both?

64. Consider the gases in problem 5. Assign the value 1 to the one which diffuses most slowly and arrange them in the order in which they diffuse, calculating a numerical value for each.

CHAPTER VIII

VOLUMES OF GASES FROM EQUATIONS

Where one or more of the final products of a chemical reaction is a gas it is frequently more desirable, from a practical standpoint, to know the *volume* of the products which will be produced from given weights of materials than to know their weights.

Example. In the reaction: $2KClO_3 \rightleftharpoons 2KCl + \uparrow 3O_2$ what weight of potassium chlorate will be necessary to produce 100 liters of oxygen at 20° C. and 740 mm. pressure?

From the equation, which is properly balanced, it may be observed that 2 gram moles of potassium chlorate produce 3 gram moles of oxygen. But from what we have already learned about gases, 3 gram moles of oxygen occupy 3×22.4 liters at N.T.P. We can then say that 2×122.5 g. of potassium chlorate will produce 67.2 liters of oxygen at N.T.P. The given volume of gas is, however, at 20° C. and 740 mm. pressure. Before we can proceed to solve the problem, the volume must be first changed to N.T.P.

100 liters of oxygen at 20° C. and 740 mm. will be

$$100 \times \tfrac{740}{760} \times \tfrac{273}{293} = 90.72 \text{ liters at N.T.P.}$$

We can then write:

$$\frac{2 \times 122.5}{x} = \frac{67.2}{90.72}$$

Solving, $$x=\frac{90.72\times 2\times 122.5}{67.2}=330.8 \text{ g.}$$

This type of problem is, as always, better solved in a systematic form as follows:

(1) Reduce the given volume to standard conditions.

(2) $2KClO_3 \rightleftharpoons 2KCl+3O_2$.

$$\frac{2\times 122.5}{x}=\frac{3\times 22.4}{90.72}$$

Solving, $$x=\frac{2(122.5)\ (90.72)}{67.2}=330.8 \text{ g.}$$

*Method.** (1) *Write and balance the equation for the reaction and consider it to take place at N.T.P.*

(2) *Reduce all gaseous volumes to N.T.P. if they are given at another temperature and pressure, or, if a volume is desired, find it first at N.T.P. and then change as required.*

(3) *Place under the formulæ of the substances in question the theoretical weights and volumes, and under these the given ones, representing the unknown quantity by an appropriate letter.*

(4) *Make a proportion in the order in which the quantities appear and solve for the unknown.*

It should be borne in mind that, while weights may be calculated from equations using any units whatsoever, provided both given and required are the same, in finding volumes from equations **weights must be in grams and volumes in liters.** (Why?)

Appropriate factors for other units are easily calculated, but it is not worth the trouble. This type of problem may also involve a series of reactions which should be made consecutive as in Chapter V, before beginning the solution, which is then obtained in the usual manner.

---

* Attempt to solve also by the "molar" method of Chapter V (q.v.)

When both substances in question are gases and only volumes are desired, this type of problem may be solved still more easily by the use of Gay-Lussac's Law.

Gay-Lussac's Law. *When two or more gases combine or react under the same conditions of temperature and pressure, the ratio by volume in which they do so is expressible by simple integers.* This law follows directly from the gas laws, the molecular theory, and Avogadro's Hypothesis, and would probably have never been stated at all if all of these had been accepted first.

Illustration. The equation $2CO + O_2 \rightleftharpoons 2CO_2$ states that 2 gram moles of carbon monoxide combine with 1 gram mole of oxygen to produce 2 gram moles of carbon dioxide.

At normal temperature and pressure, however, these weights of the gases would occupy respectively 44.8, 22.4, and 44.8 liters; i.e., at N.T.P. the ratios by volume of the reacting gases is $CO : O_2 : CO_2 = 2 : 1 : 2$. Since all gases change in volume equally for equal increments in temperature and pressure, this ratio remains constant under all conditions, provided only that the conditions are the same for all the gases.

Note that the ratio by volume is the same as the numerical coefficients of the gases in the equation.

Example. A mixture of acetylene with an excess of oxygen measures 350 cc. at 20° C. and 740 mm. pressure. After explosion, the volume of the resulting products is 275 cc. under the same conditions. Calculate the volumes of acetylene and oxygen in the original mixture.

Write and balance the equation for the reaction:

$$2C_2H_2 + 5O_2 \rightleftharpoons 4CO_2 + 2H_2O$$

Since at the temperature and pressure in question water is a liquid, its volume may be neglected, as may always the volumes of liquids and solids in similar problems, for the volume of a liquid or a solid under ordinary circumstances is negligible in comparison with that of the same weight of a gas.

(Calculate and compare the volumes occupied by 1 gram of water at 100° C. and 1 atmosphere pressure as a liquid and as a gas. To what pressure would the gas have to be subjected to make the two volumes of the same order of magnitude?)

From the equation, the ratio by volume in which the gaseous substances react is 2 : 5 : 4 in that order, or, if the original substances were mixed in exactly the proportions necessary to react, the ratio of the total original volume to the total final volume would be as 7 : 4.

There would be a contraction in volume of $7-4$ or 3 volumes; i.e., the ratio of the contraction in volume to the original volume of acetylene would be as 3 : 2, or the original volume of acetylene would be two-thirds of the contraction in volume. Read this statement through slowly and be sure you understand each step of the reasoning.

In the problem under consideration, however, the gases are not mixed in exactly the proportions required for complete combination as there is an excess of oxygen beyond that necessary to react exactly with the acetylene.

This same excess of oxygen will remain after the reaction. In other words, whereas the original volume consisted of acetylene and oxygen, the final volume will be composed of carbon dioxide and oxygen.

We may represent the unknown ratio as follows:

$C_2H_2 : O_2 : CO_2 = 2 : 5 + \text{excess} : 4 + \text{excess}.$

Total original volume: total final volume $= 7 + \text{excess} : 4 + \text{excess}.$

Contraction $= (7 + \text{excess}) - (4 + \text{excess}) = 3.$

Contraction : acetylene = 3 : 2.

Original volume of acetylene = 2/3 of contraction in volume.

But, in the problem, the contraction in volume is the difference between the original and final volumes or, 350 − 275 = 75 cc. Hence the volume of acetylene in the original mixture was 2/3 of 75 or 50 cc., and of oxygen 350 − 50 = 300 cc.

Check. From the equation, 50 cc. C_2H_2 + 125 cc. O_2 produce 100 cc. of CO_2. This uses all of the acetylene and 125 cc. of the oxygen, leaving 300 − 125 = 175 cc. of oxygen. The final volume will consist of 100 cc. of carbon dioxide and 175 cc. of oxygen or a total of 275 cc., which agrees with the problem.

In solving this type of problem it must be remembered that gaseous volumes must always be given under the same conditions of temperature and pressure, or else must be changed by the gas laws to the same conditions of temperature and pressure, which, however, need not necessarily be N.T.P.

In problems, always change to those conditions which will facilitate the solution of the problem.

PROBLEMS

1. How many grams of water are formed by burning 5 liters of hydrogen at Normal Temperature and Pressure?

2. How many liters of oxygen at N.T.P. can be obtained by heating 8.4 g. of potassium chlorate?

3. How many cubic feet of carbon dioxide would be liberated from 5 lbs. of calcium carbonate by sufficient nitric acid?

4. What weight of calcium carbide (CaC_2) would be required for the production of 2500 cu. ft. of acetylene by the action of water? What weight of the carbide would be required if it were only 87% pure?

5. How many liters of chlorine at N.T.P. are required to

liberate 49 g. of bromine from a solution of potassium bromide?

6. Find the volume of methane whose complete combustion forms 10 cu. ft. of carbon dioxide.

7. What volume of hydrogen in cubic centimeters and liters will be produced by dissolving 65 mg. of zinc in dilute sulphuric acid?

8. What weight of iron will be required to liberate 5 liters of hydrogen from hydrochloric acid?

9. At the rate of 21 volumes per 100, what volume of air would contain enough oxygen to burn exactly 25 liters of hydrogen?

10. An electric spark is passed through each of the following mixtures. What gas and how much of it remains in each case?

(*a*) Two volumes of oxygen and one volume of hydrogen.
(*b*) Two volumes of hydrogen and one volume of oxygen.
(*c*) One volume of hydrogen and one volume of chlorine.

11. How many kilograms of iron would be required to furnish enough hydrogen to fill a balloon of 6350 cu. m. capacity?

12. How many liters of oxygen are necessary for the complete combustion of 4 liters of hydrogen sulphide?

13. How many liters of ammonia may be obtained by the action of lime on 50 g. of ammonium chloride?

14. What would be the volume of each of the resulting gases if 500 cc. of ammonia were completely decomposed into its constituents?

15. How many liters of oxygen are necessary to burn 100 liters of methane, both gases being measured at the same conditions?

16. How many grams of sodium chloride must be electrolyzed to yield 5 liters of chlorine?

17. What volume of air containing one-fifth oxygen by volume would convert 100 cc. of nitric oxide into nitrogen peroxide?

18. What volume of oxygen would be necessary for the complete combustion of 1000 liters of acetylene? If air contains 21% oxygen by volume, what volume of air would be required?

19. How many liters of sulphur dioxide at N.T.P. would result from the reaction of 12 g. of copper with concentrated sulphuric acid? At 100° C. and two atmospheres pressure?

20. What weight of sodium sulphite must be treated with acid to furnish 3.5 liters of sulphur dioxide at N.T.P.? At 100° C. and one atmosphere pressure?

21. Twenty liters of air at 15° C. and 730 mm. pressure were passed through lime water and the calcium carbonate formed weighed 0.0256 g. What per cent by volume of carbon dioxide was present in the air?

22. Magnesium acting with an acid liberated 100 cc. of hydrogen at 22° C. and 780 mm. pressure. Calculate the weight of magnesium used.

23. How many grams of potassium will liberate as much hydrogen as 26 g. of sodium?

24. If a sample of bleaching powder liberated 32% of its weight of chlorine, how many liters of chlorine at N.T.P. can be obtained from a kilogram of bleaching powder?

25. How many liters of acetylene at 20° C. and one atmosphere pressure can be prepared from 10 g. of 90% pure calcium carbide?

26. How many liters of nitric oxide at 25° C. and 758 mm. pressure can be made by dissolving 80 g. of copper in dilute nitric acid?

27. How many grams of ferrous sulphide are necessary to prepare 5 liters of hydrogen sulphide at 25° C. and 752 mm. pressure?

28. How many liters of oxygen can be made by heating 122.5 g. of potassium chlorate if the temperature is 32° C. and the barometric pressure is 730 mm.? What volume would the gas actually occupy if collected over water under these conditions?

29. How many liters of chlorine at 30° C. and 760 mm. are needed to convert 12 g. of phosphorus into the trichloride?

30. A sample of moist air, confined over water at 15° C. and 760 mm., occupies 15 cc. It is mixed with 20 cc. of hydrogen, the mixture is exploded, and suffers a contraction of 9.5 cc. What would be the volume of oxygen it contained if measured dry at N.T.P.?

31. How many liters of hydrogen chloride at 31° C. and

756 mm. pressure are necessary to neutralize a solution of 10 g. of sodium hydroxide?

32. 3.5 liters of gaseous hydrofluoric acid at 10° C. and 765 mm. pressure were obtained by heating fluorspar (CaF_2) with oil of vitrol (H_2SO_4). What weight of fluorspar was used?

33. What weight of oxygen is required for the complete combustion of 24 liters of phosphine (PH_3) measured at 15° C. and 740 mm. pressure?

34. How many grams of ammonium nitrate are required to furnish enough nitrous oxide to burn 24 g. of carbon?

35. 115 cc. of oxygen were partially converted to ozone. The volume contracted to 110 cc., but when the gas was gently heated the original volume was restored. Calculate the number of cubic centimeters of ozone produced and its percentage by volume.

36. Calcium carbide (CaC_2) is treated with water and the resulting acetylene is burned. Twenty-eight liters of carbon dioxide at 15° C. and 740 mm. resulted from the combustion. How many grams of calcium carbide were taken and what volume of oxygen at 15° C. and 740 mm. was needed to burn the acetylene?

37. How many cubic centimeters of oxygen are required to unite exactly with the hydrogen produced by the decomposition of 10 g. of ammonia?

38. Sixteen cubic centimeters of a mixture of nitrogen and oxygen were added to 25 cc. of pure hydrogen and the resulting mixture was exploded. The residual gas had a volume of 23 cc. How much of the original mixture was oxygen?

39. What volume would the nitrogen which may be obtained from 22 g. of ammonium nitrite occupy at 22° C. and 756 mm. pressure?

40. At 100° C. and one atmosphere pressure, what volumes of carbon dioxide and of carbon disulphide, respectively, can be produced from 4 lbs of pure charcoal?

41. A mixture of 500 cc. of oxygen and 250 cc. of hydrogen is exploded. What gas, if any, will remain and how much of it?

42. One hundred volumes of air at N.T.P., containing 21% by volume of oxygen, are mixed with seventy volumes of hydrogen measured at 20° C. and 765 mm. pressure and an electric spark is passed through the mixture. What would be the volume of the gas remaining at N.T.P. and of what will it consist?

43. How many liters of hydrogen chloride can be made at 40° C. and 650 mm. pressure by heating 117 g. of sodium chloride to red heat with an excess of sodium bisulphate?

44. What weight of phosphorus would be necessary to remove the oxygen from 10 liters of air consisting of one-fifth oxygen by volume?

45. How many grams of potassium chlorate must be decomposed to give 36 liters of oxygen at 25° C. and 780 mm. pressure?

46. How many liters of chlorine can be made at 40° C. and 750 mm. pressure by treating 25 g. of manganese dioxide with hydrochloric acid?

47. How many cc. of nitrogen peroxide may be made at 26° C. and two atmospheres pressure from 8 g. of lead nitrate?

48. How many grams of aluminium must react with dilute sulphuric acid to produce 23 liters of hydrogen at 30° C. and one atmosphere pressure?

49. If one volume of phosphorus vapor unites with six volumes of chlorine to give four volumes of phosphorus trichloride, how many atoms are there in a molecule of phosphorus?

50. If, at the boiling point of sulphur, 1 cc. of the vapor unites with 8 cc. of oxygen to give 8 cc. of sulphur dioxide, calculate the number of sulphur atoms in a molecule.

51. The molecular formula for water is H_2O. From the fact that, all being gases under the same conditions, two volumes of hydrogen combine with one volume of oxygen to form two volumes of water vapor, prove by Avogadro's Hypothesis that if the hydrogen molecule is diatomic the oxygen molecule contains two atoms.

52. A mixture of carbon monoxide with excess oxygen measured 500 cc. at 24° C. and 760 mm. pressure. After explosion the volume of the resulting gases measured 400 cc. under the

same conditions. Calculate the volumes of carbon monoxide and of oxygen in the original mixture.

53. A mixture of phosphine with excess oxygen measured 250 cc. at 20° C. and 740 mm. pressure. After explosion the volume of the dry gaseous product measured 150 cc. at N.T.P. Calculate the volumes of phosphine and oxygen in the original mixture.

54. Potassium cyanide was added to a solution of copper sulphate and the resulting cyanogen (C_2N_2) burned to form carbon dioxide, of which 10 liters at 35° C. and 757 mm. were produced. What weight of copper sulphate was used?

55. Five liters of nitrogen peroxide at 23° C. and one atmosphere pressure were passed into a sodium hydroxide solution which was then acidified and treated with potassium permanganate. What weight of the permanganate was reduced?

56. The equations involved in the preparation of sulphuric acid by the contact process are:

$$4FeS_2 + 11O_2 \rightleftharpoons 2Fe_2O_3 + 8SO_2$$

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

$$SO_3 + H_2O \rightleftharpoons H_2SO_4$$

What volume of air which contains 20% oxygen by volume is needed at 20° C. and 750 mm. pressure for the production of a kilogram of sulphuric acid?

57. Five liters of carbon dioxide at 43° C. and 712 mm. pressure are passed through a sodium hydroxide solution which is just sufficient to absorb it. The resulting solution is evaporated to dryness, heated strongly, and treated with hydrochloric acid. What weight of sodium chloride is produced?

58. Five liters of hydrogen sulphide at 4° C. and 700 mm. pressure will produce what weight of copper sulphide when passed through a copper sulphate solution?

59. A certain volume of chlorine at 21° C. and 750 mm. pressure was passed into a potassium iodide solution and the liberated iodine reacted with 1.29 g. of sodium thiosulphate ($Na_2S_2O_3$). What volume of chlorine was used?

CHAPTER IX

SOLUTIONS

A *solution* is a homogeneous dispersion of one substance in another. The medium is called the *solvent*, the dispersed material the *solute*, and the resulting mixture the *solution*. The solute is present, in general, as molecules in the solution, and in many respects behaves as though it were a gas confined to the volume limited by the boundaries of the solution.

The strength of a solution or its *concentration*, is determined by the quantity of solute in a given volume of solution. If this is small, the solution is said to be *dilute;* if large, *concentrated.*

The numerical value of the concentration of a solution may be expressed as (1) weight of solute per unit volume of solution; (2) volume of solute per unit volume of solution; (3) per cent of solute by weight based on the weight either of the pure solvent or of the solution; (4) per cent of the solute by volume; (5) molar strength; (6) normal strength. In most cases, the weight or volume which is the basis of calculation is that of the solution and not of the solute, save in the case of solubilities.

These units may be defined and illustrated for use as follows:

(1) We may say that *a solution contains* 10 *g. of a certain solute in* 100 *cc. of solution.* This is not a very common unit for ordinary work but is widely used in analytical chemistry where the

concentration has been accurately determined. It may then be expressed, not in terms of the actual solute, but in terms of the quantity of some other substance with which the amount of solute in 1 cc. of the solution will react.

For example, potassium permanganate will oxidize ferrous iron to ferric iron. The strength of a permanganate solution is frequently given in terms of this; e.g., *1 cc. = 0.00158 g. Fe,* means that 1 cc. of the solution would be just sufficient to oxidize 0.00158 g. of iron as a ferrous salt to the ferric condition.

Solubility expressed in terms of this unit refers to the volume of solvent, which is an exception. Thus, the solubility of ordinary salt is 35.86 g. per 100 cc. of water at 18° C.

(2) A solution of a liquid in a liquid is occasionally measured as *volume of solute in* 100 *cc. or in* 1 *liter of solution.* This is not common, but is sometimes useful because the volumes of liquids are easily and rapidly determined.

(3) *Per cent by weight* is the weight of solute in a given weight of solution divided by that weight and multiplied by 100 to convert to per cent. Thus, a 10% salt solution by weight contains in every 100 g. of solution 10 g. of NaCl. This unit is sometimes taken as the weight of solute in 100 cc. of the solution which is fundamentally illogical, and is not to be recommended or employed.

(4) *Per cent by volume* is the volume of the solute per hundred volumes of the solution. This is useful where the solute is a liquid. Alcohol

solutions frequently have their concentrations expressed in per cent by volume.

(5) The *molar strength* of a solution is the number of gram moles of the solute per liter of the solution. A molar solution (written, M solution) is one containing 1 gram mole of solute per liter.

A M/2 solution of NaCl contains $\frac{1}{2} \times 58.46 = 29.23$ g. of NaCl per liter of solution; a 0.258 M solution contains $0.258 \times 58.46 = 15.08$ g. per liter. The molar strength of a solution is obtained by dividing the weight in grams of the solute in 1 liter of the solution by the molecular weight of the solute. This is one of the most common ways of expressing concentrations, for in these units they can be used for solving certain types of chemical problems without conversion.

(6) A *normal solution* is one which contains one equivalent weight of the solute per liter of the solution. The *normal strength* is the weight of solute per liter of the solution divided by the equivalent weight of the solute; *the weight of solute* in any given volume is the normal strength multiplied by the volume expressed in liters and the equivalent weight of the solute. It may be expressed in fractions or decimal fractions, or multiples of the equivalent weight. Thus, a 1.062 N solution of potassium permanganate, means one containing 1.062 equivalent weights of potassium permanganate per liter of solution. This is a most useful way to express concentrations, as equal volumes of solutions of the same normality will always just completely react, a

> perfectly obvious fact which students are prone to lose sight of. It is the same as saying that equivalent weights are equivalent which is an obvious truism.

Hence 1 liter of normal hydrochloric acid will just dissolve one equivalent weight of zinc, or react with and completely neutralize 1 liter of normal sodium hydroxide solution.

It would be well at this point to review equivalent weights for which there are a number of complementary definitions. Equivalent weight is:

a. The atomic weight of an element divided by its valence. Thus,

$$\text{Equivalent weight of iron as } FeCl_2 = \frac{55.84}{2} = 27.92.$$

$$\text{Equivalent weight of iron as } FeCl_3 = \frac{55.84}{3} = 18.60.$$

b. The weight of a substance which will combine with, react with, or displace 1.008 *g. of hydrogen or* 35.46 *g. of chlorine.* Thus,

$$CuO + H_2 \rightleftharpoons Cu + H_2O$$

$$\text{Equivalent weight of } CuO = \frac{79.57}{2} = 39.79$$

c. The molecular weight of a compound divided by the total valence of either radical, since the total valence of each is the same. Thus,

$$\text{Equivalent weight of } H_3PO_4 = \frac{98.06}{3} = 32.69.$$

d. For an oxidizing agent, the *molecular weight divided by the number of equivalent weights of oxygen furnished by* 1 *gram mole of the substance.* Since this depends upon the chemical reaction, the same oxidizing agent may have more than one equivalent weight if it can act as an oxidizing agent in different ways, as many can. Thus,

$$2KMnO_4 \rightleftharpoons K_2O+2MnO+(5O) \text{ in acid solution.}$$

$$\text{Equivalent weight of } KMnO_4=\frac{158.03\times 2}{10}=31.61.$$

$$2KMnO_4 \rightleftharpoons K_2O+2MnO_2+(3O) \text{ in alkaline solution.}$$

$$\text{Equivalent weight of } KMnO_4=\frac{158.03\times 2}{6}=52.67.$$

e. The molecular weight of an oxidizing agent divided by the number of positive charges it furnishes in the ionic equation for the reaction. (This corresponds to (*d*), but is a method for obtaining the desired quantity, which is more in accord with modern theory.) Thus,

$$MnO_4^-+8H^+ \rightleftharpoons 4H_2O^\circ+Mn^{++}+5(+)$$

$$[1(-)+8(+)=2(+)+5(+)]$$

$$[7(+)=7(+)]$$

Hence here, the equivalent weight of potassium permanganate would be the molecular weight divided by 5 from the first equation.

$$MnO_4^-+4H^+=MnO^\circ_2+2H_2O^\circ+3(+)$$

Here, the equivalent weight of potassium permanganate would be the molecular weight divided by 3. Naturally both of these results are the same as the values obtained in the last section.

(What would be the equivalent weights of $Ca(MnO_4)_2$ if employed in the same ways?)

***Example 1.** What volumes of N/ 2 and N/10 sulphuric acid must be mixed to give 2 liters of N/5 acid?

*Contractions in volume are neglected in these simple problems.

2 liters of N/5 acid contain $\frac{2}{5}=0.4$ equivalent of acid.
1 liter of N/2 acid contains $\frac{1}{2}=0.5$ equivalent of acid.
1 liter of N/10 acid contains $\frac{1}{10}=0.1$ equivalent of acid.
Let x be the volume in liters of N/2 acid required.
Let y be the volume in liters of N/10 acid required.
Then $0.5x$ = number of equivalents of acid from N/2 acid.
And $0.1y$ = number of equivalents of acid from N/10 acid.

Since the final volume required is 2 liters

$$x+y=2$$

and $$0.5x+0.1y=0.4$$

Solving, $$4x=2$$

$$x=0.5 \text{ liter};\quad y=1.5 \text{ liters}$$

Example 2. How much water would you add to 10 cc. of N/10 HCl to make it N/15?

10 cc. of N/10 HCl contain $\frac{10}{1000}\times 0.1=0.001$ equivalent of HCl.
N/15 HCl contains $\frac{1}{15}\div 1000=0.000067$ equivalent of HCl per cc.
0.001 equivalent of HCl will make $\frac{0.001}{0.000067}=15$ cc. of N/15 HCl.
Hence, to the 10 cc. of acid we must add $15-10=5$ cc. of water.

Note the answer and the normalities of the solutions. We might have said: 1.5 volumes of N/15 HCl contain the same number of equivalents of HCl as 1 volume of N/10 HCl. Hence we must add $\frac{1}{2}$ of the volume of N/10 acid, or 5 cc. of water.

Example 3. What volume of N sodium thiosulphate would react with 0.568 equivalent of iodine?

0.568 equivalent of sodium thiosulphate will react with 0.568 equivalent of iodine. Since 1 liter of the solution contains one equivalent (it is a N solution), 568 cc. will be required.

Example 4. How much hydrochloric acid of sp. gr. 1.1256 containing 24.90% of HCl could be made from 300 cc. of acid of sp. gr. 1.2134, containing 43.40% of the gas?

The required acid contains $1.1256 \times 0.249 = a$ g. HCl per cc.

The given acid contains a total of $300 \times 1.2134 \times 0.434 = A$ g. HCl

Therefore, $$\frac{A}{a} = \frac{300 \times 1.2134 \times 0.434}{1.1256 \times 0.249} = 563.3 \text{ cc.}$$

PROBLEMS

1. How many grams per liter in a tenth molar solution of sulphuric acid? In a tenth normal solution?

2. What weight of sodium chloride is present in 3 liters of a N/5 solution?

3. Concentrated hydrochloric acid, as sold commercially, contains 39% by weight of hydrogen chloride and has a specific gravity of 1.2. What is the molarity of the solution? What is its normality?

4. What is the molarity of a solution of phosphoric acid which contains 10 g. of the acid in every 100 cc.?

5. Ammonium chloride is soluble to the extent of 29.4 g. in 100 cc. of water at 0° C. What is the molar solubility of ammonium chloride per liter?

6. How many grams of sulphuric acid are present in 500 cc. of a 6 N solution?

7. Suppose you desired to make up 300 cc. of 3.5 M hydrochloric acid. What weight of the gas would be required?

8. What is the normality of a solution of silver nitrate which contains 5.63 g. of solute per liter?

9. A solution of ammonium sulphate is found to hold 12.5 g. of the solute in 125 cc. What is the molarity of the solution? What is its normality?

10. Silver chloride is soluble to the extent of 0.000152 g. in 100 cc. of water at 20° C. What is the molar solubility of the salt?

11. What weight of potash alum is present in 100 cc. of N/10 solution?

12. How much water would you add to 10 cc. of N/10 hydrochloric acid to make it N/15?

wt. g. per cc. = sp. g.

13. What is the normality of a solution of sulphuric acid which has a specific gravity of 1.83 and contains 95% by weight of the acid?

14. Determine the normality of a solution of ammonium hydroxide which has a specific gravity of 0.942 and contains 15.94% by weight of ~~ammonia~~. [illegible]

15. How many grams of ammonium chloride are necessary to prepare 3 kilograms of a solution containing 30% by weight of the substance? What would be the normality of the solution? (Sp. gr. = 0.8957.)

16. If the solubility of calcium hydroxide is 0.17 g. per 100 cc., is it possible to prepare a N/10 solution? What is the normality of the strongest solution which can be made? (Neglect the volume of the solute.)

17. What is the normality of a hydrochloric acid solution 1 liter of which will dissolve 14.26 g. of aluminium? What are the equivalent weights of the aluminium and of the acid in the reaction?

18. What weight of the hydroxyl radical is present in a liter of N/5 sodium hydroxide solution?

19. What weight of nitric acid is present in a solution of the dilute acid which is N/10 with respect to copper?

20. How many kilograms of a 30% hydrochloric acid solution can be made from 50 kilograms of sodium chloride?

21. What volume of hydrochloric acid having a specific gravity of 1.2 and what volume of water would be required to make 1 liter of acid having a specific gravity of 1.1?

22. What volumes of N/10 and N sulphuric acid would have to be mixed in order to obtain 5 liters of N/5 acid?

23. Calculate the number of grams of each of the following substances necessary to prepare a liter of the normal solution: sulphuric acid, phosphoric acid, acetic acid, potassium hydroxide, calcium hydroxide, sodium sulphate.

24. Eight grams of sodium hydroxide are contained in 50 cc. of a solution. How many grams would this be in 1 liter? What is the normality of the solution?

25. Five grams of potassium hydroxide are dissolved in

water and the volume is made up to 50 cc. What is the normality of the resulting solution?

26. Fifteen cubic centimeters of concentrated hydrochloric acid containing 39% by weight of the gas and having a specific gravity of 1.2 are diluted with water to a total volume of 60 cc. What is the normality of the resulting solution?

✓ 27. What is the normality of a solution of sodium chloride of which 1 cc. = 0.150 g.? = = [illegible]

28. What is the molarity of a solution of sodium hydroxide 1 cc. of which contains 0.021 g. of hydroxyl radical?

✓ 29. How many grams per liter are there in normal solutions of the following: KCl, $BaCl_2,2H_2O$, $AgNO_3$, H_3PO_4, $Al_2(SO_4)_3$, NH_4Cl, Na_2CO_3? 1 2 1 3 6

1 2

30. How many grams of potassium dichromate are there in a liter of a normal solution to be used for the oxidation of iron in the presence of sulphuric acid?

31. How many grams of potassium permanganate are there in 112 cc. of 0.8 N solution to be used for the determination of oxalic acid?

32. A solution of potassium dichromate to be used for the determination of iron contains 0.013 g. of the solute per cubic centimeter. Express its concentration in terms of a normal solution.

33. What is the equivalent weight of sodium thiosulphate to be used for the determination of iodine?

34. What is the equivalent weight of concentrated nitric acid in its reaction with copper?

35. Fifty cubic centimeters of a solution of sodium thiosulphate contain 2.89 g. of the solute. What is the normality of the solution as a salt?

36. If 80 g. of a solution of sulphuric acid are just sufficient to dissolve 22 g. of copper oxide, what is the percent by weight of pure sulphuric acid in the original solution?

37. How many kilograms of a 10% solution of acetic acid can be made from 10 Kg. of 80% alcohol?

38. Express the concentration of a 5% aqueous solution of

phosphoric acid, specific gravity 1.027, in terms of a normal and molar solution respectively.

39. How would you make 500 cc. of molar copper sulphate solution from blue vitriol? Remember that blue vitriol is a hydrate.

40. How would you make 250 cc. of 0.1 N potassium permanganate solution to be used for the determination of iron?

41. 450 cc. of a 0.253 N potassium dichromate solution would contain what weight of solute if it had been standardized in terms of sulphurous acid?

42. How much hydrochloric acid, specific gravity 1.1256, containing 24.90% of hydrogen chloride, could be made from 300 cc. of acid, specific gravity 1.2134, containing 43.40% of the gas?

43. What volume of nitric acid containing 12.86% of the acid and having a specific gravity of 1.0741 could be made from a liter of concentrated acid containing 67.95% of HNO_3 and having a specific gravity of 1.4112?

44. How would you proceed to prepare a liter of 6 N hydrochloric acid from 13.6 N acid?

45. How many grams of Glauber's salt are there in 800 cc. of N/5 solution? Of anhydrous sodium sulphate in the same volume?

46. How would you make a normal solution of hydrochloric acid? Of potassium hydroxide? Of barium hydroxide?

47. A merchant wants to prepare 5 liters of ammonia water, specific gravity 0.96, by diluting ammonia water having a specific gravity of 0.9. What volume of ammonia water and what volume of water should he use?

48. A kilogram of iron represents how many equivalent weights of the metal for solution in dilute sulphuric acid? For oxidation by means of potassium dichromate in acid solution?

49. A pound of sodium thiosulphate is how many equivalents to be used for the determination of iodine?

50. One kilogram of pure nitric acid represents what number of equivalent weights calculated as dilute acid?

51. How many grams of potassium permanganate are there in 1 cc. of a 0.1146 N solution?

52. What volume of a normal sodium hydroxide solution contains a sufficient quantity of the base to neutralize exactly 500 cc. of a normal hydrochloric acid solution?

53. How many cubic centimeters of a molar solution of sulphuric acid will be required to neutralize 100 cc. of normal potassium hydroxide solution?

54. What volume of normal sodium hydroxide solution will neutralize 150 cc. of a 0.5 N acetic acid solution?

55. If 25 cc. of sodium hydroxide solution react exactly with 50 cc. of 0.1 N sulphuric acid, what is the normal concentration of the base?

56. What volume of normal hydrochloric acid will be required to dissolve 1.426 equivalents of aluminium?

57. What volume of 0.1 N sodium thiosulphate solution will be required to react with 1.219 equivalents of iodine? How many grams is 1.219 equivalents of iodine?

58. What volume of 0.0985 N potassium permanganate solution would contain 1.243 equivalents of the solute?

CHAPTER X

EXPERIMENTAL DETERMINATION OF MOLECULAR WEIGHT

The determination of the molecular weights of chemical compounds is an important problem. Most methods are based upon the principles explained in the next few paragraphs, which include all of those that are important from the general chemistry viewpoint.

I. The gram molecular weight of any gas at N.T.P. occupies 22.4 liters. Hence, to obtain the molecular weight of any substance which is easily vaporized, measure the volume of any known weight as a gas at any convenient temperature and pressure. Then calculate that weight which, at N.T.P., would occupy 22.4 liters. This is the molecular weight.

Example 1. 0.9650 g. of a certain substance as a gas at 100° C. and 775 mm. pressure occupy 94.51 cc. Calculate its molecular weight.

First reduce this volume to N.T.P.

$$V_{ntp} = \tfrac{775}{760} \times \tfrac{273}{373} \times 94.51 = 70.54 \text{ cc.}$$

Remembering the fact stated above, by a proportion determine the weight of 22.4 liters (=22,400 cc.).

$$\frac{70.54}{22{,}400} = \frac{0.9560}{\text{Mol. wt.}}$$

$$\text{Mol. wt.} = \frac{0.9650 \times 22{,}400}{70.54} = 306.4$$

Note. It is occasionally useful to remember that the molecular weight in milligrams at N.T.P. occupies 22.4 cc.

II. A substance in solution behaves in many respects like a gas, and exerts an osmotic pressure (consult a text-book) equal to the gaseous pressure which it would exert if the solute were a gas confined in a volume equal to the limits of the solution.

The osmotic pressure varies with the temperature and volume of the solution (which is inversely proportional to the concentration of the solute) in the same way that gaseous pressure does.

Hence, the molecular weight of a solute is that weight which, when dissolved in a solvent to form a liter of solution at 0° C., exerts an osmotic pressure of 22.4 atmospheres. (See the note following the next section.)

Example. A solution containing 10 g. of sugar per liter exerts an osmotic pressure of 533.4 mm. of mercury at 20° C. Calculate the molecular weight of sugar.

First calculate what this pressure would be at 0° C.

$$P \text{ at } 0^\circ \text{ C.} = \tfrac{273}{293} \times 533.4 = 497.0 \text{ mm.}$$

By a proportion, calculate the weight in 1 liter necessary to cause a pressure of 22.4×760.

$$\frac{10}{\text{Mol. wt.}} = \frac{497.0}{22.4 \times 760}$$

$$\text{Mol. wt.} = \frac{22.4 \times 760 \times 10}{497.0} = 342.5$$

III. The addition of a non-volatile solute to a solvent always elevates its boiling-point and depresses its freezing-point. These changes are *colligative* properties, i.e., depend simply upon the molar concentration of the solute and not upon its nature.

Hence all molar solutions of *non-ionogens* in the same solvent freeze and boil at the same temperature, and the amount of lowering of the freezing-point and elevation of the boiling-point per mole of solute is a constant, characteristic of the solvent. For water these are respectively −1.86° C. and +0.52° C.

The molecular weight of a solute in water is therefore that weight of solute which, when dissolved in water to make 1 liter of solution, freezes at −1.86° C. and boils at 100.52° C. This fact enables us to calculate the molecular weight of a solute from certain other experimentally obtainable data.

Note. These values, for other reasons, are sometimes taken as the constants for solutions containing a gram mole of solute in 1000 grams of solvent not 1000 cubic centimeters of solution. This is especially applicable to problems dealing with concentrated solutions. Remember this fact, and apply it where it is necessary in solving problems.

Example. 9.216 g. of a certain substance in 100 cc. of its aqueous solution boils at 100.26° C. What is the molecular weight of the substance?

$$9.216 \text{ g. in } 100 \text{ cc.} = 92.16 \text{ g. per liter}$$

Hence,
$$\frac{92.16}{\text{Mol. wt.}} = \frac{0.26}{0.52}$$

Or,
$$\text{Mol. wt.} = \frac{0.52}{0.26} \times 92.16 = 184.32$$

Example. What strength of a phenol solution, C_6H_5OH, would have the same osmotic pressure at 25° C. as a 2% cane-sugar ($C_{12}H_{22}O_{11}$) solution? Assume the sp. gr. of the solution to be 1.

(*a*) Solutions of the same molar concentration have the same osmotic pressures at all temperatures, since osmotic pressure varies directly with the absolute temperature.

(*b*) A 2% cane-sugar solution contains $0.02 \times 1000 = 20$ g. per liter. This is $\frac{20}{342}$ M.

(*c*) Hence the phenol solution should contain $\frac{20}{342}$ moles of phenol per liter, or $\frac{20}{342} \times 94 = 5.5$ g. per liter which is, roughly, 0.55%.

PROBLEMS

1. What is the molecular weight of the gas the vapor density of which at N.T.P. is 14?

2. If a certain gas is 1.44 times as heavy as air at N.T.P., what is its molecular weight?

3. What is the molecular weight of the gas whose density is 1.276 g. per liter at N.T.P.?

4. Calculate the molecular weight of the gas the vapor density of which is 7.19 at 20° C. and 760 mm. pressure.

5. If 1 liter of a certain gas weighs 2.78 g. at 22° C. and 745 mm. pressure, what is its molecular weight?

6. If 275 cc. of a gas at 25° C. and 715 mm. pressure weigh 0.46 g., calculate the molecular weight of the gas.

7. A certain gas is 14.4 times as heavy as hydrogen at 23° C. and 765 mm. pressure. What is its molecular weight?

8. A 500 cc. flask of air weighed 40.495 g. at 18° C. and 740 mm. pressure. When filled with ether vapor at 50° C. and 740 mm. it weighed 41.2605 g. Calculate the molecular weight of ether.

9. The density of methyl alcohol vapor at 64.7° C. and 760 mm. pressure is 1.21 g. per liter. What is its molecular weight?

10. A liter flask when filled with chloroform vapor at 61° C. and 760 mm. pressure weighed 65.93 g. The same flask when evacuated weighed 61.50 g. What is the molecular weight of chloroform?

11. In a Victor Meyer vapor density apparatus 0.1387 g. of a compound vaporized to a volume equal to 47.2 cc. of dry air at 24° C. and 755 mm. pressure. What is the molecular weight of the compound?

12. What is the molecular weight of the gas 180 cc. of which weigh 0.235 g. at N.T.P.?

13. A Dumas bulb of 300 cc. capacity was filled with vapor from an easily volatilized liquid at 45° C. The barometer stood at 740 mm. What was the molecular weight of the liquid if the gas weighed 1.25 g.?

14. A student placed some potassium chlorate in a test tube and heated it, collecting the oxygen which he obtained in a eudiometer tube over water. He found that the test tube lost weight to the extent of 0.1716 g. while the volume of the oxygen he obtained was 124.5 cc. at 15° C. and 757 mm. pressure. From these data calculate his determination of the molecular weight of oxygen. What was his percentage error?

15. 250 cc. of a certain substance as a gas at 118° C. and 756 mm. pressure weigh 0.7875 g. What is the molecular weight of the substance?

16. In a Dumas bulb of 200 cc. capacity, filled with the vapor of a certain liquid at 80° C. and 758 mm. pressure, it was found that the vapor weighed 0.550 g. What was the molecular weight of the liquid?

17. One liter of steam at 100° C. and 760 mm. pressure weighs 0.596 g. What is the molecular weight of water vapor?

18. If 250 cc. of air at 25° C. and 730 mm. pressure weigh 0.2244 g., what is the weight of the G.M.V.? What would then be the molecular weight of air if it were a compound and not a mixture?

19. Determine the molecular weight of the substance 0.2345 g. of which as a gas collected over water, occupy 241 cc. at 24° C. and 756 mm. pressure.

20. Determine the osmotic pressure at 25° C. of a solution of urea (CON_2H_4) containing 5 g. of the solute per liter.

21. What should be the osmotic pressure at 12° C. of a solution of cane sugar ($C_{12}H_{22}O_{11}$) containing 19 g. of the solute per liter?

22. A 2% solution of cane sugar has an osmotic pressure of 101.6 cm. at 15° C. What is the molecular weight of cane sugar?

23. An aqueous solution of orthoboric acid has an osmotic pressure of 27.3 cm. of mercury at 0° C. If the solution contains 1.004 g. of acid per liter, what is the molecular weight of the solute?

24. What should be the osmotic pressure at 30° C. of a grape sugar ($C_6H_{12}O_6$) solution containing 10 g. of the solute per liter?

25. If a solution of glycerine at 0° C. exerted an osmotic pressure of 36.7 cm. of mercury, determine the concentration of the solution.

26. What strength of a phenol solution (C_6H_5OH) would have the same osmotic pressure at 25° C. as a 2% cane sugar ($C_{12}H_{22}O_{11}$) solution? Assume the specific gravity of the solution to be 1.

27. 2.3 g. of a certain substance, dissolved to form 300 cc. of solution, upon experiment gave a solution with an osmotic pressure of 456.7 mm. of mercury. What is the molecular weight of the substance? The temperature was 26° C.

28. 4.21 g. of a substance were dissolved in a total volume of 1435 cc. and a measurement of the osmotic pressure of the solution was made at 31° C. It was found to be 528.5 mm. of mercury. What was the molecular weight of the solute?

29. In 1911 Morse found that at 10° C. various solutions of cane sugar exerted osmotic pressures as follows: 0.1 M, 2.5 atmospheres; 0.5 M, 12.3 atmospheres; 1.0 M, 25.69 atmospheres. Show from these observations that the osmotic pressure of a solution varies directly as the concentration (i.e., $p = kC$ or $p/C = k$. What is the value of k here?)

30. A solution of 2.39 g. of a substance in a total volume of 489 cc. exerts an osmotic pressure of 43.2 cm. of mercury at 19° C. What is the molecular weight of the substance?

31. From the values given in problem 29, determine directly the osmotic pressure of a 0.2 M solution of cane sugar. Do the same for an 0.8 M solution. How do these agree with the values that you calculate by the method used in this chapter?

32. What would be the osmotic pressure of a 1% solution of metaphosphoric acid (HPO_3) at 15° C.?

33. What should be the molar concentration of a solution which boils at 100.15° C.?

34. If a solution of 23.5 g. of a certain substance in a liter of solution freezes at −0.85° C., what is the molecular weight of the substance?

35. If 5 g. of a substance dissolved in 1000 cc. of water give a solution with a freezing point of −0.2° C., what is the molecular weight of the substance?

36. Six grams of a substance when dissolved in water to make a total volume of 200 cc. give a solution with a boiling point of 100.6° C. What is the molecular weight of the solute?

37. A solution of 0.2735 g. of hydrogen peroxide in 19.86 g. of water lowered the freezing point of the water 0.746° C. What is the molecular weight of hydrogen peroxide? (See note, page 83.)

38. What weight of cane sugar would have to be dissolved in a liter of solution to give a freezing point of −2.2° C.?

39. What is the molar concentration of a solution which boils at 101.6° C.?

40. 6.39 g. of a non-electrolyte, dissolved in water to give a total volume of 1000 cc., freezes at −0.279° C. What is the molecular weight of the substance in question?

41. 1.6 g. of naphthalene ($C_{10}H_8$) when dissolved in 25 g. of benzene (F.P. 5.48° C.) gives a solution which freezes at 3.03° C. When 2.44 g. of another substance are dissolved in the same amount of benzene the solution freezes at 3.52° C. What is the molecular weight of the latter substance?

42. If a solution made by dissolving 8 g. of a substance to make a total volume of 1000 cc. freezes at −0.4° C., what is the molecular weight of the substance?

43. What should be the boiling point of a solution of cane sugar containing 150 g. of sugar in 800 cc. of solution?

44. What should be the freezing point of all 0.5 M solutions?

45. What should be the boiling point of all 0.1 M solutions?

46. 7.20 g. of a substance dissolved in 100 g. of water give a solution with an osmotic pressure of 9.65 atmospheres at 22° C. Calculate the molecular weight of the substance and also the temperature at which this solution would freeze.

47. At what temperature would the solution in problem 46 boil?

48. A solution, 600 cc. of which contains 41.5 g. of solute, has an osmotic pressure of 4.51 atmospheres. At what temperature would this solution boil?

49. At what temperature would the solution in problem 48 freeze?

50. What would be the osmotic pressure of a solution whose freezing point is −0.82° C.?

51. What would be the boiling point of a solution the osmotic pressure of which is 12.45 atmospheres?

52. Determine the concentration (molar), freezing point, and osmotic pressure of a solution which boils at 100.34° C.

53. 1.426 g. of a certain substance are dissolved in 25.94 g. of water and the freezing point of the solution is determined. It is found to be 1.764° on a thermometer which registers the freezing point of pure water as 2.392°. What is the observed molecular weight of the material?

54. What should be the molecular weight of a substance in order that a solution which contained 22 g. of it per liter shall have an osmotic pressure of 65.1 cm. of mercury at 25° C.?

55. If 1.791 g. of a certain substance as a gas over water at 30° C. and 726 mm. pressure occupy a volume of 98.4 cc., what is the molecular weight of the substance?

56. 2.069 g. of a solid, when dissolved in 30.43 g. of water, yield a solution with a boiling point of 2.319° on a thermometer which indicates the boiling point of pure water as 2.008°. What is the molecular weight of the substance?

57. What should be the freezing point, boiling point, and osmotic pressure at 0° C. of a 1% by weight solution of hydrogen peroxide? Assume that the specific gravity of the solution is the same as that of pure water. Would these be the same if the formula of hydrogen peroxide were HO? Does this indicate one method of verifying the correct formula of a substance?

CHAPTER XI

ATOMIC WEIGHTS AND ANALYTICAL CALCULATIONS

Atomic Weights

The Determination of Atomic Weights. Dulong and Petit's Law enables us to determine roughly the order of magnitude of the atomic weight of an element if it is a solid and its specific heat is known.

Dulong and Petit's Law. *The product of the atomic weight and the specific heat of an element is approximately a constant whose value is between* 6 *and* 7 (about 6.5).

While this law is of little actual value for the accurate determination of these constants, it serves as an excellent check on the order of magnitude, since the equivalent weight of an element is easily measured by comparison with the equivalent weight of some element for which this value is accurately known, provided, of course, that the unknown element can be made to combine with some such element.

Example 1. 3.0420 g. of silver combine with 1.0000 g. of chlorine. The specific heat of silver is 0.056 calorie per gram. What is the atomic weight of silver?

The atomic weight of chlorine is 35.46 and, as chlorine is univalent, this is also its equivalent weight. The equivalent weight of silver is that weight which will combine with 35.46 g. of chlorine.

$$\frac{\text{Eq. wt. Ag}}{35.46}=\frac{3.0420}{1.0000}$$

$$\text{Eq. wt. Ag}=\frac{3.0420}{1.0000}\times 35.46=107.88$$

$$107.88\times 0.056=6.0$$

Hence, according to Dulong and Petit's Law, 107.88 is the atomic as well as the equivalent weight of silver, or its valence is one. If this product had been 3, the atomic weight would have been twice the equivalent weight, and a corresponding multiple for any other aliquot part.

If an element forms a number of easily volatilized compounds, its atomic weight may be obtained by measuring the molecular weights of these compounds and the percent of the element in question in each compound. From these two quantities, by multiplication, the weight of the element whose atomic weight is unknown, in the molecular weight of each compound may be found.

If a sufficiently large number of compounds is examined, it will be highly probable that one will be found which contains in its molecule only one atom of the element. Since the atom is, by definition, indivisible, no compound will ever be found which contains in its gram molecular weight a smaller weight of the element than this compound, and the weights of the element in the molecular weights of all other compounds will be whole number multiples of this weight, which is then taken as the atomic weight.

Of course, this is based on probability alone. If it should happen that a compound contained a smaller weight than the accepted atomic weight in its gram molecular weight, it would be necessary to revise the atomic weight of the element, but this does not occur.

Example 2. The following compounds of the element *E* have molar weights and contain the percentages of *E* indicated. From this data what is the probable value of the atomic weight of *E*?

A. Molar weight, 119.39, *E* 10.05%; B, 26.02, 92.23%; *C*, 16.03, 74.92%; *D*, 78.05, 92.25%; *E*, 54.05, 88.0%.

Weight of *E* in mol. wt. A $= 119.39 \times 0.1005 = 12.0$
Weight of *E* in mol. wt. *B* $= 26.02 \times 0.9223 = 24.0$
Weight of *E* in mol. wt. *C* $= 16.03 \times 0.7492 = 12.0$
Weight of *E* in mol. wt. *D* $= 78.05 \times 0.9225 = 72.0$
Weight of *E* in mol. wt. E $= 54.05 \times 0.8880 = 48.0$

The smallest weight of *E* in any of the above gram molecular weights is 12.0 grams. This divides an even number of times into the weight contained in all of the molecular weights and the atomic weight of *E* is therefore 12.0.

Since, in general, the discovery of new elements is a comparatively rare occurrence, while the atomic weights of the elements already known are constantly undergoing revision as the accuracy of our experimental methods increases, the first method is by far the more important. In fact the problem of determining the atomic weight of an element may be reduced, in nearly all cases, to the accurate determination of the proportion in which it combines with some element whose atomic weight is known very accurately.

Analytical Calculations

After the experimental work has been done, the determination of the atomic weight of an element is really a problem in analytical calculations. These may be divided into two groups: **gravimetric** problems, or those which deal with weights, and **volumetric** problems, or those which deal with volumes of solutions of known and unknown concentrations, respectively. The number of types of problems in these two groups is large. Any given problem can usually be resolved into portions involving two or more of the simple principles which have been reviewed in the preceding chapters.

Before attempting to solve a problem which very evidently does not belong to any of the simple types in Chapters I–X, it should be read over very carefully. When the student is certain that he understands just what is desired, he should then decide upon the steps necessary to accomplish that end, thus dividing the question into a number of simpler ones which may then be solved individually. A number of examples follow.

Example 1. 0.3826 g. of crude soda ash required 45.61 cc. of 0.1420 N HCl to react with and neutralize it. What per cent of sodium carbonate was present in the sample?

45.61 cc. of acid solution contained $\frac{45.61}{1000} \times \frac{36.47}{1} \times 0.1420$ g. HCl.

To simplify the calculation, call this weight A.

$$Na_2CO_3 + 2HCl \rightleftharpoons 2NaCl + H_2O + \uparrow CO_2$$

$$\frac{106}{x} = \frac{2 \times 36.47}{A}$$

Solving, $x = \frac{A \times 106}{2 \times 36.47}$ grams Na_2CO_3 required to react with A grams of HCl and therefore the quantity contained in the original sample.

$$\% \ Na_2CO_3 = \frac{A \times 106 \times 100}{2 \times 36.47 \times 0.3826} =$$

$$\frac{45.61 \times 36.47 \times 0.1420 \times 106 \times 100}{2 \times 36.47 \times 0.3826 \times 1000} = 89.72\%$$

This problem may also be solved as follows:

45.61 cc. of 0.1420 N HCl contained $\frac{45.61}{1000} \times 0.1420$ equivalent of HCl which would react with and neutralize $\frac{45.61}{1000} \times 0.1420$ equivalent of sodium carbonate. The equivalent weight of sodium carbonate is $\frac{106}{2} = 53$.

$$\text{Weight of } Na_2CO_3 \text{ in sample is } \frac{53 \times 45.61 \times 0.1420}{1000}$$

$$\% \; Na_2CO_3 = \frac{53 \times 45.61 \times 0.1420 \times 100}{1000 \times 0.3826} = 89.72\%$$

Example 2. How many cubic centimeters of N/5 sodium thiosulphate solution will be required to react with the iodine liberated by 20 cc. of N/10 potassium dichromate solution?

Since the thiosulpuate solution is twice as strong as the dichromate, the volume required will be $\frac{20}{2} = 10$ cc.

Note. In this type of problem care must be used to see that the substances have the same equivalent weights in all reactions involved. Review the introduction to the chapter on Solutions, and see the next problem.

Example 3. A sample of iron wire is dissolved out of contact with air in 30 cc. of HCl of which 1 cc. = 0.95 cc. N/2 HCl. The iron requires 40 cc. of N/10 potassium dichromate for oxidation. What excess of HCl was used over that required for solution?

Since 1 cc. of this solution = 0.95 of N/2 HCl, its normality is $\frac{95}{100} \times 0.5 = 0.475$.

It must be noted here that the equivalent weights of iron in the two reactions in question are different. In dissolving in HCl we have

$$Fe^\circ \rightleftharpoons Fe^{++} - 2(^+), \text{ and its equivalent weight is } \frac{55.84}{2} = 27.92$$

Dichromate oxidizes ferrous iron to ferric iron:

$$Fe^{++} = Fe^{+++} - 1(^+), \text{ and the equivalent weight is } 55.84$$

40 cc. of N/10 dichromate contain $\frac{40}{1000} \times 0.1 = 0.004$ equivalent of dichromate which will, in turn, react with 0.004 equivalent of iron (equivalent weight 55.84) which will therefore require 0.008 equivalent of HCl for solution.

30 cc. of 0.475 N HCl contain $\frac{30}{1000} \times 0.475 = 0.01425$ equivalent of HCl.

Hence we had $0.01425 - 0.008 = 0.00625$ equivalent of HCl beyond that necessary for solution.

Since 1 cc. of 0.475 N HCl contains 0.000475 equivalent, the excess HCl was $\frac{0.00625}{0.000475} = 13.1$ cc.

We might have said: 40 cc. of N/10 $K_2Cr_2O_7$ were required. Since the equivalent weight is twice as great as toward HCl, 80 cc. of N/10 HCl would be required for solution, or 16 cc. of N/2 HCl, which would be $\frac{100}{95} \times 16 = 16.9$ cc. of the given solution. The excess was then $30 - 16.9 = 13.1$ cc.

PROBLEMS

1. Dumas and Stas obtained 59.3765 g. of carbon dioxide by burning 16.192 g. of carbon. If the atomic weight of oxygen is 16, what is the atomic weight of carbon?

2. What is the approximate atomic weight of an element if its specific heat is 0.033? If it is 0.0952?

3. Calculate the specific heats of the following elements from Dulong and Petit's Law: gold, nickel, potassium, lead, zinc.

4. 100 g. of sulphur when heated with copper gave 298.27 g of copper sulphide (CuS). If you knew only that the atomic

weight of sulphur was 32.06 and the atomic weight of copper was in the neighborhood of 60–70, how could you determine the exact atomic weight of copper?

5. Berzelius oxidized 25 g. of lead and obtained 26.925 g. of lead monoxide (PbO). What is the atomic weight of lead?

6. Use the following data to calculate the approximate atomic weight of nitrogen:

	Wt. of 1 l. in g.	% N
Nitrogen	1.256	100
Nitric oxide	1.34	46.67
Nitrous oxide	1.97	63.64
Ammonia	0.762	82.35

If the equivalent weight of nitrogen is 4.67, what is its exact atomic weight?

7. The specific heat of lithium is 0.941; of potassium, 0.166; of carbon, 0.485; of iron, 0.114; of cobalt, 0.107; of nickel, 0.108; of tin, 0.054; of mercury, 0.032; and of lead, 0.031. Assuming Dulong and Petit's constant to be in each case 6.4, calculate the atomic weights of these elements.

8. The specific heat of arsenic is 0.0814 and its vapor is 9.37 times as heavy as oxygen. How many atoms are there in its molecule?

9. The analysis of barium chloride furnishes 35.5 parts of chlorine to 68.7 parts of barium. The specific heat of barium is 0.0465. What is the atomic weight of barium if that of chlorine is 35.5?

10. The percentage composition of platinum chloride is: platinum, 57.7%; chlorine, 42.3%. The specific heat of platinum is 0.0324. What is the atomic weight of platinum if that of chlorine is 35.46?

11. The molecular weight of litharge is 223.1. Its percentage composition is: lead, 92.8%, and oxygen, 7.2%. If the specific heat of lead is 0.031, calculate its exact atomic weight.

12. From the following data calculate the atomic weight of hydrogen:

	Wt. of 1 l. in g.	% H
Hydrogen chloride	1.61	2.74
Hydrogen bromide	3.61	1.23
Hydrogen	0.09	100.0
Hydrogen sulphide	1.542	5.88
Ammonia	0.762	17.65
Marsh gas	0.717	25.00

13. If 118.3938 g. of mercuric oxide yield, when heated, 109.6308 g. of mercury, what is the atomic weight of mercury?

14. 0.5 g. of zinc, when dissolved in hydrochloric acid, liberated 183.7 cc. of hydrogen measured over water at 15° C. and 760 mm. pressure. What is the atomic weight of zinc if that of hydrogen is 1.008?

15. If 3.17 g. of iron form 4.53 g. of ferric oxide (Fe_2O_3), what is the atomic weight of iron?

16. When 1 g. of sodium burns, it produces 1.7 g. of the oxide. If the oxide contains two atoms of sodium in the molecule, what is the atomic weight of sodium?

17. An oxide of a certain metal is found to contain 53.8% of the metal. If the molecule of the oxide contains three atoms of oxygen, what is the atomic weight of the metal?

18. If 5.6040 g. of silver unite with 0.9867 g. of fluorine, calculate the atomic weight of fluorine, assuming that of silver.

19. If 4.2237 g. of silicon combine with 4.7763 g. of oxygen, what is the equivalent weight of silicon? If its valence is four, what is its atomic weight?

20. If 0.3697 g. of aluminium liberated 0.04106 g. of hydrogen on being dissolved in a strong solution of sodium hydroxide, what is the atomic weight of aluminium?

21. An oxide of bismuth contains 89.66% of bismuth; calculate the equivalent weight of bismuth. If its valence is three, what is its atomic weight?

22. A sample of lead is dissolved in nitric acid, to which an excess of hydrochloric acid is added, and the resulting solution is evaporated to dryness. The following observations are made:

Weight of dish and lead = 7.5180 g.
Weight of dish and lead chloride = 7.6953 g.
Weight of dish = 7.0001 g.

Determine the equivalent weight of lead. If the specific heat of the metal is 0.031, what is its atomic weight?

23. By experiment it is found that 0.5335 g. of nickel will produce 0.8250 g. of nickel sulphide. If the formula of nickel sulphide is NiS, what is the atomic weight of nickel?

24. Stas found that after adding 7.25692 g. of potassium chloride to 10.51995 g. of silver dissolved in nitric acid, 0.0194 g. of silver remained in the solution. Calculate from these data the atomic weight of silver.

√ 25. Twenty-one cubic centimeters of a normal solution of nitric acid were added to and exactly neutralized 15 cc. of a solution of potassium hydroxide. How many grams of potassium hydroxide per liter did the solution contain?

√ 26. If it takes 63 cc. of a normal sodium hydroxide solution to neutralize the sulphuric acid in 20 cc. of a certain solution, what is its normality? How many grams per liter of sulphuric acid did it contain?

√ 27. For the neutralization of 77 cc. of a certain alkaline solution, 25 cc. of normal hydrochloric acid are required. What is the normal concentration of the alkali? If the alkali was sodium hydroxide, how many grams per liter were present? If the alkali was barium hydroxide, how many grams per liter were present?

28. Five grams of potassium hydroxide are dissolved in a total volume of 60 cc. What is the normality of a dilute hydrochloric acid solution which requires 21.53 cc. of this solution to neutralize the acid contained in 15 cc.?

29. What volume of the potassium hydroxide solution in problem 28 would be required to neutralize the hydrochloric acid in 10 cc. of the concentrated acid, of specific gravity 1.2, containing 39% by weight of the acid?

30. 15.2 cc. of 0.2 N sulphuric acid were required to neutralize 18.7 cc. of a solution of ammonium hydroxide. What was the normality of the latter?

31. The equivalent weight of potassium is 39. How many grams of hydrogen are formed when 5 g. of it react with water? How many grams of water are used up? How much potassium hydroxide is formed?

32. Suppose we have a molar solution of sodium hydroxide and a hydrogen chloride solution of unknown strength. If 50 cc. of the former require 62 cc. of the latter for neutralization, what is the strength of the acid solution?

33. How many cubic centimeters of a 0.1 N hydrochloric acid solution are required to neutralize 80 cc. of a 0.5 N potassium hydroxide?

34. 300 cc. of a solution of caustic potash containing 40 g. of the solute per liter are required to neutralize 100 cc. of a solution of sulphuric acid and also the same volume of nitric acid solution. What are the normalities of the two solutions?

35. When 1.336 g. of calcium react with water, 800 cc. of hydrogen are collected over water at 15° C. and 753 mm. pressure. Calculate the equivalent weight of calcium.

36. If 44.00 cc. of a sulphuric acid solution neutralize 30 cc. of normal potassium hydroxide solution, what is the normality of the acid? How many grams of the acid are there per liter of solution?

37. Thirty-five cubic centimeters of a solution of potassium permanganate containing 15 g. per liter were required to oxidize 50 cc. of an acidified solution of ferrous sulphate to ferric sulphate. What was the amount of metallic iron in a liter of the ferrous sulphate solution?

38. Twenty cubic centimeters of a solution of hydrogen peroxide, after acidification with dilute sulphuric acid, reduced 24 cc. of 0.1 N potassium permanganate. Calculate the percent of hydrogen peroxide in the solution.

39. How many cubic centimeters of a solution of potassium permanganate containing 40 g. of solute per liter are necessary to oxidize 0.5 g. of iron from the ferrous to the ferric state?

40. 16.3 cc. of N/2 sodium hydroxide solution were required

to neutralize 10.5 cc. of a solution of sulphuric acid. One cubic centimeter of the acid solution contains how many grams of sulphuric acid?

41. In an experiment, 13.98 g. of iron were dissolved in dilute sulphuric acid, and the hydrogen which was formed measured 5.6 liters at N.T.P. What is the equivalent weight of iron?

42. If 0.056 g. of iron are dissolved in dilute sulphuric acid, how much potassium permanganate is required to oxidize the resulting solution from the ferrous to the ferric state?

43. How much iron is present in a solution which requires 47 cc. of an M/4 solution of potassium permanganate to produce a pink color?

44. If 150 cc. of a solution of potassium permanganate are just decolorized by 150 cc. of a solution of hydrogen peroxide (3% by weight), how many grams of the permanganate were used and what was the normality of the permanganate? Assume that the density of the peroxide solution is 1.

45. What volume of 0.1236 N sodium thiosulphate solution is required to react with 1.236 g. of free iodine?

46. 2.35 g. of copper sulphate are treated with excess of potassium iodide solution, and the free iodine is titrated with 0.4245 N sodium thiosulphate solution. What volume of the latter was used?

47. Express the concentration of a 0.0996 N solution of potassium permanganate in terms of grams of iron per cubic centimeter.

48. Express the concentration of a 0.1126 N solution of sodium thiosulphate in terms of grams of iodine per cubic centimeter.

49. Ten grams of a sample of coal, on analysis, yield 0.6217 g. of $BaSO_4$. What was the per cent of sulphur in the coal?

50. How many cubic centimeters of 0.9587 N hydrochloric acid will be required to dissolve 1.65 g. of limestone which is 91% pure?

51. What volume of 0.2156 N potassium dichromate solution will oxidize the same quantity of iron as 31 cc. of 0.1156 N potassium permanganate solution?

52. One gram of a certain alloy, on analysis, yields 0.7891 g.

of lead sulphate. What is the per cent of lead in the alloy?

53. 45.00 cc. of a 0.0985 N potassium permanganate solution are added to excess potassium iodide, and the free iodine is titrated with a sodium thiosulphate solution, of which 23.47 cc. are required. Express the normality of the thiosulphate solution.

54. A solution of sodium hydroxide is titrated with an oxalic acid solution of which 1 cc. is equal to 1.45 cc. of 0.8546 N potassium permanganate solution. Equal volumes are used. What is the normality of the alkali?

55. Five grams of potassium hydroxide are dissolved in water and the volume is carefully made up to 100 cc. The resulting solution is used to titrate a solution of oxalic acid, and it is found that 1 cc. of base is equal to 0.95 cc. of acid. The acid is then titrated with a potassium dichromate solution of unknown strength, and the determination is made that 1 cc. of oxalic acid is equal to 1.24 cc. of the oxidizing agent. Express the normality of the potassium dichromate solution and also the weight per liter of the solute.

56. A mixture of barium oxide and calcium oxide weighing 0.2438 g. yields 0.4876 g. of mixed sulphates. What is the per cent of each oxide in the mixture?

57. What volume of N sodium chloride solution will be required to precipitate exactly all of the silver from a solution of silver nitrate containing 5.46 g. of solute per liter?

58. A sample of pyrolusite when treated with hydrochloric acid yielded a quantity of chlorine equivalent to 31.5 cc. of 0.1 N sodium thiosulphate solution. If the sample weighed 0.1829 g., what per cent of manganese dioxide did it contain?

59. If nitrous acid is passed into a potassium iodide solution until the liberated iodine is equal to 55.5 cc. of 0.2367 N sodium thiosulphate solution, what weight of the acid was added?

60. A solution of copper sulphate is treated with potassium iodide and the free iodine is titrated with sodium thiosulphate. If the latter solution has a concentration of 0.2128 N, express its concentration in terms of grams of copper per cubic centimeter. If the original weight of copper sulphate was 1 g., what volume of solution was used?

CHAPTER XII

IONIZATION

The theory of ionization, it will be recalled, consists essentially of four assumptions:

1. Certain substances (*ionogens*), in aqueous solution, break up into particles smaller than molecules (*ions*).
2. These particles carry electrical charges, positive and negative respectively, each ion having one unit of charge for each unit of valence.
3. The process is reversible, and its degree increases with dilution.
4. The ions are independent, save for their electrical charges, and have their own individual properties.

The fact that the process is reversible makes it possible to apply to ionization the same principles that are used in considering other reversible equilibria, e.g., *LeChatelier's Theorem, Van't Hoff's Law*, and the *Law of Mass Action* (q.v.).

Since it is in connection with the third of these important statements that most of the problems dealing with ionization arise, it may be well to restate it here.

The Law of Mass Action. *In any reversible chemical reaction at equilibrium, the temperature and pressure being constant, the product of the molar concentrations of the final products raised to powers equal to their coefficients in the chemical equation, divided by the molar concentrations of the starting substances raised to similar powers, is a constant.*

Consider the ionic reaction

$$HC_2H_3O_2 \rightleftharpoons H^+ + C_2H_3O_2^-.$$

Applying the Law of Mass Action, we have:

$$\frac{{}^{*}C_{H^+} \times C_{C_2H_3O_2^-}}{C_{HC_2H_3O_2}} = K\dagger$$

This constant is called the Ionization Constant.

If we consider the cases of difficultly soluble substances, such as silver chloride, we have:

$$AgCl \rightleftharpoons Ag^+ + Cl^-$$

$$\frac{C_{Ag^+} \times C_{Cl^-}}{C_{AgCl}} = K$$

Now, it can be shown that in a saturated solution of a difficultly soluble substance the concentration of the molecular portion is constant, and since the saturated solution of a difficultly soluble substance is very dilute, we can, without introducing a large error, consider the ionization of the substance to be complete. The first part of this statement enables us to rewrite the expression just given as:

$$C_{Ag^+} \times C_{Cl^-} = K$$

This is known as the *Solubility Product Law*, and the con-

---

[*] In solutions containing very small amounts of H^+ its concentration is frequently expressed in *Sorensen units*. These are indicated by P_{H^+} and are negative exponents of 10 times the molar concentration; thus, $P_{H^+} = 3$ is a concentration of H^+ equal to 10^{-3} moles per liter.

[†] In general, the molecular portion may be considered to be practically the same as the original concentration. The expression then becomes $C_{H^+} \times C_{C_2H_3O_2^-} = K$.

stant as the constant of that law. It may be stated in words as follows:

Solubility Product Law. *In the saturated solution of a difficultly soluble substance, the temperature and pressure remaining constant, the product of the molar concentrations of the ions of that substance raised to powers equal to the respective numbers of each ion furnished by* 1 *gram mole of the substance in ionizing, is a constant.*

The second part of the statement referred to above enables us to calculate easily the value of this constant. The calculation of Ionization Constants is also an important type of problem dealing with ionization.

Degree of Ionization. The degree of ionization of an ionogen may be calculated from the freezing-point, boiling-point, or osmotic pressure of its solutions, using the principles outlined in connection with the determination of molecular weight.

It can readily be shown, from Avogadro's Hypothesis that the number of molecules in the gram molecular weight of all substances is the same. We should, then, expect that the molar depression in the freezing-point of the solution of an ionogen would be two, three, or four, etc., times as great as the depression of the freezing-point of a solution of a non-ionogen of the same molar concentration, since, assuming ionization to be complete, there would be two, three, or four, etc., times as many particles of ions present, depending upon the number furnished by one mole of the solute. But ionization is not, in general, complete. Let us see then if we can obtain an expression from which it can be determined from experimental data of this nature.

Consider a *molar* solution of an ionogen such as NaCl which furnishes two ions for every molecule that ionizes, and call the degree of ionization, i.e., the fraction of the mole ionized, n. Then the actual molar concentrations of each of the ions Na^+ and Cl^- respectively will be n and that of the un-ionized part of the NaCl will be the difference between the original one mole and the fraction ionized, i.e., $(l-n)$. Hence the actual concentration of particles in this solution will not be molar, as in the case of a molar solution of a non-ionogen, but will be $2n+(1-n)$, or $(1+n)$. We should then expect the lowering of the freezing-point of the solution to be greater than the molar lowering of $-1.86°$ C., in the ratio of $1+n : 1$. If we actually determined the freezing-point, we could calculate n by the ratio:

$$\frac{1.86}{\text{Obs. F.P.}}=\frac{1}{1+n}\ *$$

A similar expression can be easily deduced regardless of the number of ions furnished per molecule of the ionogen, and, needless to say, the expression could be applied to the boiling-point or osmotic pressure of the same solution. (The student should work out the expression for 1 : 2, 1 : 3, 2 : 3, etc., salts using the same reasoning.)

Example 1. An M/2 solution of sodium chloride freezes at $-1.678°$ C. Determine the degree of ionization of NaCl at this concentration.

Since NaCl is a 1 : 1 salt of the type considered above:

$$\frac{0.93}{1.678}=\frac{0.5}{0.5(1+n)}$$

or, $$0.93(1+n)=1.678$$

Solving, $$n=\frac{1.678-0.93}{0.98}=0.80$$

---

* This refers to a **molar** solution. For any solution of a 1 : 1 salt of molar concentration C, the total ionic and molecular concentration would be given by $(1+n)C$, and the true freezing point should be $-1.86°$ C, but will be $1.86(1+n)C$.

Example 2. An M/10 solution of acetic acid is ionized to the extent of 0.013. Calculate the Ionization Constant of acetic acid.

$$C_{H^+} = 0.1 \times 0.013$$

$$C_{C_2H_3O_2^-} = 0.1 \times 0.013$$

$$C_{HC_2H_3O_2} = 0.1 \times (1 - 0.013)$$

$$K = \frac{(0.1 \times 0.013)(0.1 \times 0.013)}{0.1 \times (1 - 0.013)} = 0.0000171$$

Example 3. The molar solubility of silver chloride is 0.000009. What is its solubility product?

As above, assuming its ionization to be complete:

$$C_{Ag^+} = 0.000009$$

$$C_{Cl^-} = 0.000009$$

$$K = 0.000009 \times 0.000009 = 81 \times 10^{-12}$$

Example 4. The solubility product of silver chloride has been determined to be 1×10^{-10}. What is the maximum molar concentration of silver ion which can exist in a solution which is 0.1 N with respect to chloride ion?

(*a*) When the product of $C_{Ag^+} \times C_{Cl^-} > S.P._{AgCl}$, precipitation occurs.

(*b*) Since here $C_{Cl^-} = 0.1$ from the problem (normality and molarity being the same for univalent Cl^-),

$$C_{Ag^+} \times 0.1 = 1 \times 10^{-10}$$

Hence, $$C_{Ag^+} = \frac{1 \times 10^{-10}}{0.1} = 1 \times 10^{-9} \text{ moles per liter.}$$

PROBLEMS

1. If a normal solution of nitric acid is 82% ionized, what is the weight of nitrate ions in 30 cc. of solution?

2. If a normal hydrochloric acid solution is 78.4% ionized, what is the normal concentration of the solution with respect to hydrogen ion?

3. If permanganic acid is 93.3% ionized in half normal solution, what weight of hydrogen ion is present in 25 cc. of 0.478 N solution?

4. What volume of normal potassium hydroxide solution, 77% ionized, contains the same weight of hydroxyl ion as 1 liter of normal sodium hydroxide solution, 73% ionized?

5. What is the normality with respect to the hydroxyl ion of a N/64 solution of barium hydroxide which is 0.92 ionized?

6. What volume of hydrobromic acid will contain 1 g. of hydrogen ion if the acid is N/2 and is 89.9% ionized?

7. Phosphoric acid is ionized to the extent of 17% in N/2 solution. What is the normality of this solution with respect to the hydrogen ion?

8. Sodium chloride is 0.86 ionized in 0.1 N solution. What volume of this solution will contain the same weight of chloride ions as a liter of normal hydrochloric acid which is 78.4% ionized?

9. Express the normalities of the normal solutions of the following acids in terms of the hydrogen ion: nitric acid, 82% ionized; hydrochloric acid, 78.4%; sulphuric acid, 51%; hydrofluoric, 7%.

10. Calculate the "ionization constant" for hydrochloric acid which, in normal solution, is 78.4% ionized. (This is *not* a constant for strong acids, strong bases, and most salts.)

11. Calculate the ionization constant for acetic acid which is ionized to the extent of 0.4% in 0.1 N solution.

12. The ionization constant of nitrous acid is 0.0005. What is its degree of ionization in normal solution?

13. The ionization constant for the first step of the ionization of phosphoric acid is 0.01. What is the degree of ionization

of the acid with respect to this first step into 0.1 N solution? (Consider the acid to be monobasic.)

14. What is the ionization constant of an acid which is ionized to the extent of 0.2% in N/10 solution? The acid is monobasic.

15. What is the degree of ionization in a normal solution of a monobasic acid the ionization constant of which is 0.000018.

16. What is the solubility product of lead sulphate if its molar solubility is 0.0041, assuming it to be completely ionized?

17. 100 cc. of water hold 0.00013 g. of silver chloride. What is the solubility product of the substance if it is completely ionized?

18. What is the molar solubility of a 1 : 1 salt which has a solubility product of 0.00256?

19. The solubility product of a certain 1 : 1 salt is 0.0000025. What is its molar solubility? What weight of the salt would be held in 100 cc. of a saturated solution?

20. Calcium oxalate is soluble in water to the extent of 0.00055 g. in 100 cc. Assuming it to be completely ionized at this dilution, what is its solubility product?

21. Silver chromate has a molar solubility of 0.00015. Calculate its solubility product.

22. Determine the solubility product of silver chromate from the fact that 100 cc. of water will dissolve 0.0025 g.

23. Calcium carbonate has a molar solubility of 0.00013. What change in its solubility product would there be if it were only 92% ionized in a saturated solution?

24. An aqueous solution of lithium chloride containing 8.5 g. of the solute in 100 cc. of solution boils at 101.97° C. What is the percentage dissociation of the salt?

25. If potassium chloride in molar solution is 74.9% ionized, at what temperature would the solution freeze?

26. At what temperature would the solution in problem 25 boil?

27. What is the degree of dissociation of zinc sulphate if 5 g. of it, dissolved in 125 cc. of aqueous solution, freezes at −0.603° C.?

28. What is the freezing point of a normal solution of hydrochloric acid (78.4% ionized)?

29. What is the boiling point of a normal solution of sodium hydroxide (73% ionized)?

30. In a decinormal solution, potassium chloride is 86% ionized. What is the freezing point of the solution?

31. If sodium chloride is ionized to the extent of 82% at this dilution, how many grams would be required to form a liter of a solution boiling at 100.52° C.?

32. If potassium hydroxide is 77% ionized, what weight would be required to form a liter of solution freezing at $-1.86°$ C.? What weight would be required if it were not ionized at all?

33. If potassium iodide is ionized to the extent of 80% at this dilution, how many grams must be dissolved to give 100 cc. of a solution freezing at $-0.93°$ C.?

34. The solubility product of silver chloride is 1.5×10^{-10}. What is the maximum molar concentration of silver ion which can exist in a solution which is 0.1 N with respect to the chloride ion?

35. Taking the solubility product of silver chloride as given in problem 34, determine the maximum concentration of silver ion which can exist in a normal hydrochloric acid solution (78.4% ionized).

36. The solubility product of barium sulphate is 1×10^{-10}. What is the maximum molar concentration of barium ion which can exist in a molar solution of potassium sulphate if the latter is 70% ionized?

37. How many grams of silver chromate, solubility product 2.6×10^{-12}, can remain dissolved in 1000 liters of a N/10 solution of silver nitrate which is 86% ionized?

38. Silver bromide has a solubility product of 4.4×10^{-13}. How many grams will remain dissolved in 1000 liters of a 0.5 N solution of hydrobromic acid which is 89.9% ionized? Compare this weight with that which would dissolve in the same volume of water.

39. A certain solution of potassium nitrate is ionized to the extent of 86% and freezes at $-3.41°$ C. What is its molar concentration?

40. A solution of barium hydroxide, ionized to the extent of

92%, freezes at −0.0186° C. What is its molar concentration? What is its normal concentration?

41. If a 0.1 N solution of barium chloride is 72% ionized, what weight of silver chloride (S.P. 1.5×10^{-10}) can dissolve in 1 liter of it?

42. If the solubility products of magnesium carbonate and magnesium oxalate are, respectively, 2.6×10^{-5} and 8.5×10^{-5}, which solution can hold the larger concentration of magnesium ion without precipitation, if the degree of ionization is the same: N/10 potassium oxalate or N/ 10 potassium carbonate?

43. Would one drop (0.2 cc.) of a 0.001 N solution of magnesium chloride, if added to a liter of 0.01 N sodium carbonate solution (85% ionized), produce precipitation? See problem 42 for additional data if necessary. Assume the magnesium chloride to be completely ionized.

44. What concentration of lead could exist in equilibrium with a normal solution of sulphuric acid, 51% ionized? (The S.P. of lead sulphate is 1×10^{-8}.)

45. The solubility products of the silver halides are: silver chloride, 1.5×10^{-10}; silver bromide, 4.4×10^{-13}; silver iodide, 9×10^{-17}. Determine the concentration of silver ion which could exist in equilibrium with solutions which were 0.1 N with respect to each of the halide ions.

CHAPTER XIII

ELECTROCHEMICAL PROBLEMS

Electricity is a form of energy and, like the other forms of energy, a given quantity of it may be converted into an equivalent quantity of any other form, and will give just so much of that, and no more. In general, a device for converting a form of energy which is available into another form which is useful or desired is called a **machine.**

Most chemical reactions either liberate or absorb heat in quantities dependent upon the quantities of materials used and the nature of the reaction. The expression

$$H_2+O_2 \rightleftharpoons H_2O_2+45{,}300 \text{ calories}$$

is a thermochemical equation. It states that when 1 gram mole of hydrogen reacts with 1 gram mole of oxygen to produce hydrogen peroxide, there is an evolution of 45,300 calories of heat. If double the molecular quantities were used, double the heat would be evolved.

This quantity of heat is equivalent to approximately 180,000 coulombs of electrical energy at a potential of one volt; i.e., if these substances were made to react in such a way as to produce electrical energy instead of heat energy, 180,000 coulombs of electrical energy would be produced. Chemical reactions may be arranged in such a way as to produce or absorb electrical instead of heat energy, and the device in which this is accomplished is known as a cell.

A **cell** is, then, a chemical machine in which the heat of a chemical reaction may be utilized to furnish electrical energy, or into which we may put electrical energy in order to cause a chemical reaction to take place. The essential parts of a cell are two electrodes, one positive and the other negative, and two electrolytes or solutions surrounding the electrodes (the electrolyte may be the same solution for both). Cells may be of several kinds, and are usually classified according to the nature of the chemical reaction which they employ.

Two points of interest in the solution of problems are the potential of the cell and the quantity of electrical energy which may be obtained from it. Without discussing the theory of cells, it may be said that the potential of any cell is always the algebraic difference between the potentials of its electrodes. The second question, the quantity of electricity to be obtained from any cell, is the more common problem in general chemistry, as problems relating to the electromotive force may be quite complicated and advanced in nature. Most problems of this type may be solved by reference to **Faraday's Law,** which may be stated as follows:

To liberate equivalent weights of all ions requires the same quantity of electrical energy. This quantity of electrical energy is 96,500 coulombs.

Example 1. How much heat could be obtained from 96,500 coulombs of electrical energy at a potential of 1 volt?

$$\text{Heat} = 0.24 \times E \times I \times t$$

$$I \times t = \text{coulombs} = 96{,}500;\ E = 1 \text{ volt}$$

Hence, $96500 \times 0.24 = 23{,}160$ calories.

Example 2. How many hours will it take for a current of 1 ampere to deposit 1.680 g. of copper from copper sulphate solution?

$$\text{Equivalent weight of copper} = \frac{63.57}{2} = 31.79$$

Let x = no. of hours required.

Then $x \times 60 \times 60 \times 1$ = number of coulombs.

To liberate 31.79 g. of copper requires, by Faraday's Law, 96,500 coulombs.

Hence,
$$\frac{x \times 60 \times 60 \times 1}{96,500} = \frac{1.680}{31.79}$$

Solving,
$$x = \frac{1.680 \times 96.500}{31.79 \times 3600} = 1.42 \text{ hours}$$

PROBLEMS

1. The equivalent heat of neutralization of all strong acids and bases is 13,500 calories. If a cell were set up in which this reaction yielded electrical energy at a potential of 5 volts, what quantity of electricity would be furnished?

2. Neglecting losses, what would be the total heat of the chemical reactions involved in charging or discharging a 100-ampere-hour, 6-volt, radio A battery?

3. A current of 1 ampere flowing for 100 hours represents how many coulombs of electrical energy?

4. How long would a current of 2.5 amperes have to flow in order to give a total of 96,500 coulombs?

5. A current of 1 ampere at the proper voltage would deposit what weight of silver from a solution in 5 minutes? In 1 hour?

6. How many coulombs of electricity are required to decompose 45 g. of copper sulphate?

7. How many amperes of current will deposit 0.01118 g. of silver per minute?

8. How many amperes of current will deposit 0.02276 g. of copper per minute?

9. What weight of silver will be deposited from a solution of silver nitrate by a current of 2 amperes in 30 minutes?

10. One ampere of current would deposit what weight of tin from a solution of stannous chloride in 24 hours?

11. How long a time would be required for a current of 2 amperes to deposit 25 g. of copper?

12. Assuming a 100-ampere-hour storage battery to give

80% of its capacity safely before having to be charged, what weight of cobalt could be deposited from a cobalt chloride solution in this time?

13. If a storage battery can give 3 amperes of current for 25 hours, how many equivalent weights of the materials upon the electrodes undergo a change?

14. How many amperes of current would be required to deposit 50 g. of zinc in 3 hours?

15. If a certain current deposits 5.116 g. of copper in 2 hours, what weight of silver would be liberated in the same time? How many amperes were passing?

16. The heat of formation of zinc chloride is 97,400 calories. At a potential of 5 volts this would furnish how many coulombs of electrical energy?

17. In problem 16, what weight of zinc could be obtained from zinc sulphate by this quantity of electricity.

18. The heat of formation of lead monoxide is 50,300 calories per gram mole. At a potential of 2 volts, how many coulombs of electrical energy would this be?

19. A two-step Radiotelephone receiving set usually draws about 3.4 amperes from the storage battery. If a silver nitrate cell were connected in series with the battery, what weight of silver would be deposited during an evening program lasting 3 hours?

20. With 5 amperes of current, what time, in hours, would be required to deposit 55.84 g. of iron from a ferric chloride solution? From a ferrous sulphate solution?

21. A current of 1 ampere would liberate what weight of iodine in 30 minutes from a potassium iodide solution?

22. If a current of 2.5 amperes was passed through a potassium iodide solution for 5 minutes and the free iodine was titrated with normal sodium thiosulphate solution, what volume was required?

23. How long would it take an electric current of 3 amperes to deposit as much copper from a solution as 5 g. of zinc would?

24. A gram of radium gives off about 2.25 calories of heat every minute of its existence. At a potential of 1 volt, how

long would it take a gram of radium to produce 100 coulombs of electrical energy, if it could be arranged to do so?

25. What volume of hydrogen at 15° C. and 740 mm. pressure can be obtained in 30 minutes from acidulated water by using a current of 2 amperes?

26. How long will it take a current of 1 ampere to liberate a sufficient volume of chlorine to displace 1.2 g. of iodine from a solution of potassium iodide?

27. An electric current of 1.8 amperes is passed through acidulated water until the volume of the mixed gases measures 341 cc. at 20° C. and 740 mm. pressure. How many hours did the current flow?

28. 5.68 g. of copper oxide are dissolved in sulphuric acid and a current of 2 amperes is passed through the solution for 30 minutes. What weight of copper sulphate remains in the solution?

29. How long will it take a current of 5 amperes to remove all of the silver from a liter of N/10 solution?

30. What length of time in hours will be required for a current of 2 amperes to produce 3.47 liters of hydrogen at N.T.P. from acidulated water?

31. A current of 1 ampere will require what length of time to deposit all of the copper from 3.25 g. of copper chloride dissolved in water?

32. A solution of potassium chloride is electrolyzed for 1 hour with a current of 2 amperes. What volume of normal sulphuric acid would be required to neutralize the potassium hydroxide formed?

33. A certain weight of sodium peroxide when treated with water liberates 10 liters of oxygen at 20° C. and 750 mm. How long would it take a current of 3.5 amperes passing through a dilute acid to do the same?

34. What current would be required to liberate 2.4 cc. of hydrogen per minute at N.T.P.?

35. If a current of 10 amperes flowed for 2 hours through a solution of hydrochloric acid, what volume of chlorine would be liberated at 40° C. and 765 mm. pressure?

36. What length of time would an electric current of 1

ampere have to flow in order to oxidize as much iron as 40 cc. of N potassium permanganate?

37. Compare the time in hours required by a current of 2 amperes to deposit 1 g. of metal from solution of (*a*) ferrous ion; (*b*) ferric ion; (*c*) cupric ion; (*d*) stannic ion; (*e*) stannous ion.

38. An electric current deposits 56.2 g. of cadmium from a cadmium sulphate solution in 1 hour. What volume of hydrogen at 91° C. and 1140 mm. pressure will the same current liberate from sulphuric acid solution in 4 hours? This current deposits 17.09 g. of iron from an iron solution in 1 hour, what is the valence of the iron in this solution?

39. A current passes for 1 hour through a solution of copper sulphate and through one of orthophosphoric acid. From the latter solution 12 liters of hydrogen at 91° C. and 950 mm. pressure are liberated. What weight of copper is deposited in the copper sulphate cell? How many coulombs pass in 30 seconds?

40. What current is necessary to liberate 800 cc. of hydrogen at 50° C. and 740 mm. pressure from acidified water in 3 hours? How much copper would be deposited from a cupric sulphate solution by this current in the same time?

41. A current liberates 96.5 g. of silver from a silver nitrate solution. How many grams of copper will it deposit from a cupric sulphate solution?

42. A current liberates 224 liters of hydrogen at 15° C. and 600 mm. pressure from sulphuric acid solution. What weight of copper will the same current deposit in the same time from cupric sulphate solution?

43. How many grams of copper (from $CuSO_4$), silver, and zinc will be deposited by a current which liberates 25 liters of hydrogen from acidified water?

44. An electric current passing through a dilute solution of copper sulphate liberates 12.0 liters of oxygen at 27° C. and 750 mm. Find the weight of copper deposited.

45. The same current passing through a copper and a bismuth solution deposits 3 g. of copper. What weight of bismuth will be liberated?

CHAPTER XIV

SPECIAL TYPES

The problems in this chapter serve as a general review of all of the principles in the preceding chapters. Although at a glance some may seem radically different from those we have already considered, it will be found that no new principles are involved. All may be solved upon the basis of the knowledge and practice which should have been acquired in arriving at this point.

PROBLEMS

1. 2.4 liters of a gas at 0° C. and 76 cm. pressure are shaken with 50 cc. of N barium hydroxide solution. After the removal of the precipitate the remaining alkali required 35 cc. of 0.01 N acid to neutralize it. Find the volume of carbon dioxide in 10,000 volumes of the gas.

2. Alcohol, a liquid at ordinary temperatures, is readily converted into a gas. 0.247 g. of the gas have a volume of 184.9 cc. at a temperature of 150° C. What is the molecular weight of the gas? What is its vapor density? Alcohol is composed of carbon, 52.2%; hydrogen, 13.0%; oxygen, 34.8%. Determine its formula.

3. Dumas found that water contains 88.864% of oxygen. Show that this corresponds to H_2O, when $H = 1.000$ and $O = 15.96$.

4. By dissolving 0.4442 g. of cobalt in an acid, 177.4 cc. of hydrogen at 10° C. and 750 mm. pressure are obtained. The specific heat of cobalt is 0.107. Calculate its atomic weight.

5. What volume of sulphur dioxide at 20° C. and 760 mm.,

saturated with water vapor, can be obtained by burning 160 g. of iron pyrites?

6. 200 cc. of oxygen measured over mercury at 20° C. and 762 mm. pressure were passed through an ozonizer and the volume of the resulting gas was found to have become 182 cc. at 0° C. and 740 mm. pressure. What per cent by volume of the original oxygen was converted into ozone?

7. How many cubic centimeters of 10% by volume sulphuric acid (sp. gr. 1.07) are necessary to produce 2000 cc. of hydrogen? How many amperes are necessary to liberate this volume of hydrogen from acidified water in 1 hour?

8. A substance has the following percentage composition: C, 65.45%; H, 5.45%; O, 29.09%. Its vapor density is 55. What is its true formula?

9. Calculate the number of cubic centimeters of C.P. nitric acid (sp. gr. 1.53) that is needed to make up 1 liter of a normal solution for each of the reactions illustrated in the following cases: (*a*) as an ionogen; (*b*) concentrated acid on copper; (*c*) dilute acid on copper; (*d*) dilute acid on magnesium; (*e*) dilute acid on zinc.

10. 1.60 g. of a certain gaseous monobasic acid liberate 481 cc. of carbon dioxide at 20° C. and 760 mm. pressure from C.P. calcium carbonate. Calculate the molecular weight, vapor density, and specific gravity of the gas, and the weight of calcium carbonate used.

11. A substance shows upon analysis to contain: carbon, 24.24%; hydrogen, 4.04%; chlorine, 71.72%. One liter of its vapor at 110° C. and one atmosphere pressure weighs 3.20 g. Calculate its formula.

12. How many cubic centimeters of hydrogen at 27° C. and 780 mm. pressure, measured over water, can be obtained from the interaction of 10 g. of magnesium with excess hydrochloric acid?

13. What volume of oxygen would be necessary for the complete combustion of 10 liters of propane (C_3H_8)? What volume of air would be required? All volumes are to be measured at the same temperature and pressure.

14. From the following data calculate the percentage of "active chlorine" in a sample of bleaching powder: 10 g. of the powder were extracted with 500 cc. of water; 25 cc. of the extract, when added to an acidified solution of potassium iodide, set free iodine equivalent to 32.7 cc. of 0.1 N solution of sodium thiosulphate.

15. On heating strongly 0.406 g. of potassium chlorate, 139 cc. of oxygen were obtained, and the remaining potassium chloride weighed 0.247 g. The oxygen was measured over water at 27° C., at which temperature the vapor tension of water is 2.66 cm. The barometric height was 71.14 cm. Find the value of the molecular weight of oxygen from this experiment, and the formula for potassium chlorate.

16. 0.418 g. of a metal M, when dissolved in hydrochloric acid, liberated 534 cc. of hydrogen measured at 12° C. and 770 mm. pressure. The specific heat of the metal is 0.21 and the vapor density of its chloride is 133. Find (*a*) its equivalent weight; (*b*) its atomic weight; (*c*) the molecular formula of its chloride.

17. A compound of phosphorus, oxygen, and chlorine contained 20.19% of phosphorus, 10.43% of oxygen, and 69.38% of chlorine. The vapor density of the compound as a gas was 77.95, and the specific heat of phosphorus is 0.17. Find the molecular formula of the compound and the atomic weight of phosphorus.

18. The current from a battery liberates in a given time 150 cc. of mixed gases at N.T.P. from acidified water. If the same current were passed through copper sulphate solution, what weight of copper would be deposited?

19. 100 g. of a solution of hydrogen peroxide in water gave off, when heated, 5 liters of oxygen at N.T.P. Find the per cent of hydrogen peroxide in the solution.

20. 100 cc. of a mixture of carbon monoxide and carbon disulphide vapor were mixed with 300 cc. of oxygen and exploded. After cooling, the resulting gases occupied 340 cc., and, after absorption by potash, 200 cc. of oxygen remained. Show how the composition of the mixture may be obtained from each

of the following data: (*a*) the contraction; (*b*) the absorption; (*c*) the oxygen consumed.

21. How long will it take a current of 2 amperes, passing through a solution of sodium chloride, to generate enough chlorine to produce 100 g. of potassium chlorate by the reaction:

$$3Cl_2+6KOH \rightleftharpoons 5KCl+KClO_3+3H_2O$$

22. A tenth-normal solution of cadmium chloride is ionized to the extent of 72%. The solubility product of cadmium sulphide is 3.6×10^{-29}, and the primary and secondary ionization constants of hydrogen sulphide are 9×10^{-8} and 1×10^{-15} respectively. Determine the maximum concentration of hydrogen ion which will permit the precipitation of cadmium sulphide in a N/10 solution of the chloride.

23. Repeat the calculation in problem 22 for zinc if the S.P. of zinc sulphide is 1.2×10^{-23} and the other data, including ionization of the salt, are the same.

24. Make the calculation of problem 22 for iron if the S.P. of ferrous sulphide is 3.7×10^{-19} and the ionization of the N/10 salt is the same.

25. 160 g. of iron pyrites containing 40% of sulphur are burned. How many liters of gas would be obtained at +273° C. and atmospheric pressure?

26. A substance upon analysis is found to contain: C, 40.0%; H, 6.7%; O, 53.3%. Its vapor density at N.T.P. is 30. Calculate its formula.

27. What volume of carbon dioxide at 250° C. and 900 mm. pressure will be produced by the action of excess hydrochloric acid on 56 g. of baking soda?

28. What volume of gas at N.T.P. will be produced by the complete combustion of 100 liters of ethane (C_2H_6) measured at 22° C. and one atmosphere pressure?

29. The vapor densities of three substances are 45, 70, and 25, and the percentages by weight of a certain element contained in each are 22.22, 42.86, and 40.0, respectively. What is the probable value of the atomic weight of the element?

30. 0.428 g. of one of the oxides of manganese, when heated with hydrochloric acid, gave 42 cc. of chlorine at N.T.P. Which oxide of manganese was used?

31. One liter of mercury vapor at standard temperature and pressure weighs 8.923 g. On heating 118.3938 g. of mercuric oxide, Erdmann and Marchand obtained 109.6308 g. of mercury. On the assumption that mercuric oxide is formed by the union of one atom of mercury with one atom of oxygen, what light do these facts throw on the atomic and molecular weights of mercury?

32. 0.35 g. of a liquid that is easily vaporized has in the gaseous form a volume of 99.7 cc. (corrected). The substance is composed of 92.3% of carbon and 7.7% of hydrogen. Determine the formula of the substance.

33. What would be the weight of water in 500 cu. m. of air saturated at 23° C. and at a pressure of 760 mm.?

34. 59.1 cc. of a certain gas weigh 0.1630 g. at 50° C. and two atmospheres pressure. Calculate the molecular weight of the gas, its density, and specific gravity at N.T.P.

35. The equations for the contact process for preparing sulphuric acid are given in problem 56, Chapter VIII. From these equations calculate (*a*) the weight of sulphuric acid obtainable from 1 Kg. of iron pyrites; (*b*) the volume of air at 20° C. and one atmosphere pressure required in the process.

36. 0.55 g. of a certain gas have a volume of 277.7 cc. at N.T.P. The gas is composed of 63.6% of nitrogen and 36.3% of oxygen. What is its formula?

37. From 1 g. of pure iron 1.43 g. of an oxide are formed. Find (*a*) the percentage composition of the oxide, (*b*) its simplest formula.

38. A mixture of acetylene with an excess of oxygen measured 350 cc. at 25° C. and 745 mm. pressure. After explosion, the volume of the dry gaseous product read 307.3 cc. at 60° C. and the same pressure. Calculate the volume of acetylene and of oxygen in the original mixture.

39. A substance contains C, 10.04%; H, 0.83%; Cl, 89.13%. Its vapor density is 59.75. Find its formula.

40. Baking soda and cream of tartar in baking powder react as follows:

$$NaHCO_3 + KHC_4H_4O_6 \rightleftharpoons NaKC_4H_4O_6 + H_2O + \uparrow CO_2$$

How much baking soda is required for 47 g. of cream of tartar? What volume of carbon dioxide at 20° C. and one atmosphere pressure will this free?

41. Name the gases formed and compute their volumes, when 10 liters of methane (CH_4) completely react with oxygen.

42. What current would be required to liberate from hydrochloric acid in 3 hours the same quantity of chlorine as 5 g. of potassium permanganate?

43. If 4.265 g. of anhydrous barium chloride weigh 5.000 g. when hydrated, find (*a*) the per cent of water of hydration, (*b*) the number of molecules of water of hydration to one molecule of barium chloride.

44. If 126 g. of copper react with an excess of dilute nitric acid, calculate (*a*) the weight of copper nitrate formed, (*b*) the volume of nitric oxide at N.T.P.

45. The weight of 500 cc. of a gas at N.T.P. is 0.76 g. Calculate (*a*) its molecular weight, (*b*) its vapor density at 20° C. and 712 mm. pressure.

46. Five grams of sodium hydroxide are dissolved in a total volume of 50 cc. To 15 cc. of this solution are added 16.25 cc. of 2.67 N sulphuric acid. What volume of 0.01 N potassium hydroxide will be required to neutralize the excess acid?

47. Compare the cost of making nitric acid from potassium nitrate and from sodium nitrate with the former at 44¢ per kilogram, the latter at 33¢ per kilogram, and sulphuric acid at 11¢ per kilogram.

48. If a factory uses daily 100 tons of coal that contains 2% of sulphur, assuming that all of the sulphur is converted to sulphuric acid, what weight of the acid will the products of combustion contain during a 300 days' run?

49. How many amperes are flowing in a circuit which in 2 hours and 40 minutes has liberated 60.192 g. of copper from copper sulphate solution?

50. How much less than its true weight will be the apparent weight of 100 g. of iron (sp. gr. 7.88) in air, if 1 liter of air weighs 1.29 g.?

51. A flask of total capacity 500 cc. is evacuated, sealed off, and weighed in air with brass weights, sp. gr. 8.40. The total of the weight is 49.9720 g. Remembering that the weights are also buoyed up by the air, what is the true weight of the flask?

52. A current of electricity liberates in a given time 166.7 cc. of mixed gases from acidified water at 91° C. and 712 mm. pressure. How many coulombs were used? How much copper could be liberated from copper sulphate solution by the same current in double the time?

53. A bar of gold (sp. gr. 19.3) weighed 10.73685 Kg. when weighed in air with brass weights (sp. gr. 8.40). What is its true weight?

54. A current is passed through acidified water and liberates 18,667 cc. of hydrogen at 91° C. and 608 mm. pressure in 1 hour. How many coulombs were used? What is the strength of the current in amperes? How much zinc would react with an excess of dilute sulphuric acid to produce the same amount of hydrogen?

55. How many cubic centimeters of a 1.18 N solution of potassium dichromate will be required to oxidize 5 g. of ferrous sulphate to ferric sulphate?

56. A mixture of acetylene with an excess of oxygen measured 240 cc. at +24° C. and 752.4 mm. pressure. After explosion the volume of the dry product was 221.8 cc. at +28° C. and 750.1 mm. pressure. Calculate the volume of acetylene in the original mixture.

57. What must be the diameter of a spherical balloon which, when filled with hydrogen, will have an ascensional force of 80 Kg., the balloon itself weighing 30 Kg.?

58. Lead iodide is soluble in 190 times its mass of boiling water. How much potassium iodide and lead nitrate must be dissolved in 250 cc. of water to allow the precipitate just to redissolve on boiling?

59. Ten grams of a liquid acid precipitated 2.26 g. of silver

chloride from a solution of silver. What percentage of hydrogen chloride did the solution contain?

60. How many liters of sulphur dioxide at 450° C. and 780 mm. pressure will be formed from the complete combustion of 10 g. of hydrogen sulphide?

61. Oil of vitriol of sp. gr. 1.773 contains 70% of sulphuric acid; how many kilograms of such acid may be made from 150 Kg. of pyrites containing 42% of sulphur?

62. How many cubic centimeters of 0.42 N barium hydroxide solution are required to neutralize 275 cc. of a solution of hydrochloric acid, sp. gr. 1.13, containing 26% of HCl by weight?

63. What volume of potassium hydroxide solution containing 100 g. of KOH per liter will just neutralize 100 cc. of hydrochloric acid containing 200 g. of HCl per liter?

64. A compound has the following percentage composition: C, 62.2%; H, 10.4%; O, 27.6%. One liter of the substance, when vaporized, weighs 5.22 g. (corrected). Find its formula.

65. How large a flask may be filled with pure bromine vapor at atmospheric pressure if 5 c.c. of liquid bromine (sp. gr. 3.19) are poured into the flask, which is then immersed in boiling water?

66. What volume of hydrogen sulphide at 740 mm. and +20° C. is necessary to precipitate the Cu^{++} as the sulphide from 50 cc. of a copper sulphate solution that is 0.75 M?

67. Hydrochloric acid in normal solution is 78.4% ionized; sodium hydroxide is 73% ionized at the same dilution; sodium chloride is 82% ionized in N/2 solution. Compare the freezing points of the acid, base, and the salt solution formed by the reaction of equal volumes of each.

68. 137 cc. of barium hydroxide solution containing 36 g. of the solute per liter were required for the neutralization of 18 cc. of hydrochloric acid. What was the normality of the acid?

69. If sodium chloride is soluble to the extent of 36 g. per 100 cc. of solution at the temperature involved and is 70% ionized at this concentration, what is the lowest temperature which can be obtained with salt brine? What is the osmotic pressure of this solution at this temperature?

70. How many liters of air at 754 mm. and 24° C. are required to burn completely the hydrogen sulphide resulting from the action of hydrochloric acid on 12 g. of ferrous sulphide?

71. Assuming the ionization to be the same, and the solubility to be 120 g. per 1000 cc. of solution, make the calculations of problem 69 for potassium nitrate.

72. 0.5 g. of potassium dichromate was necessary to oxidize the ferrous iron derived from a 2 g. sample of an iron alloy. Calculate the percentage of iron in the alloy.

73. What must be the molar concentration of a solution of calcium chloride which freezes at −48° C. if it is 72% ionized? What is the osmotic pressure of this solution at this temperature?

74. What volume of normal sodium hydroxide solution is necessary to neutralize 98 cc. of M sulphuric acid?

75. What is the weight of 179.2 liters of chlorine at 182° C. and 912 mm. pressure? How long will it take a current of 10 amperes to liberate this amount of chlorine from a solution of barium chloride?

76. A solution of potassium hydroxide contains 0.02 g. of KOH per cc. and 15 cc. of it neutralize 40 cc. of an HCl solution. Find the number of grams of hydrogen chloride in 80 cc. of the solution.

77. Burette No. 1 is filled with a solution of sodium hydroxide of known strength (1 cc. contains 0.0319 g. of sodium hydroxide); 15 cc. are run into a beaker containing 50 cc. of water, and a few drops of litmus solution are added. A solution of sulphuric acid of unknown strength is then run in from burette No. 2, with stirring, until the color changes. This operation is repeated five times. The readings of burette No. 2 are: 15.1 cc., 14.8 cc., 14.7 cc., 14.7 cc., 14.6 cc. Find the average of the determined weight of sulphuric acid in 1 cc. of the solution in burette No. 2. What is the percentage deviation?

78. One gram of a certain substance, when heated, loses 0.2118 g. of water. The remaining anhydrous substance is found to have a molecular weight of 134 and shows the following percentage composition: Na, 34.33%; C, 17.76%; O, 47.91%. What was the formula of the original substance?

79. What weight of sulphuric acid is necessary to produce sodium sulphate and 15 liters of hydrogen chloride at 25° C. and 780 mm. pressure? If the acid has a specific gravity of 1.8 and contains 90% of pure solute, what volume should be used?

80. Ten cubic centimeters of a solution of copper sulphate are placed in a beaker and an excess of potassium iodide is added. The free iodine is then titrated with a solution of sodium thiosulphate until a starch solution just fails to show a blue color. If the thiosulphate was 0.1141 N and 16.72 cc. were used, what weight of copper was present in a liter of the original solution?

81. If concentrated hydrochloric acid has a density of 1.2 and contains 39% by weight of hydrogen chloride, how would you make up a liter of 6 N acid? What volume of this acid would react with 4 g. of sodium hydroxide? What weight of sodium chloride would be produced?

82. What weight of oxygen is required to burn 1 ton of coal which is 95% carbon? If air is 20% oxygen by volume, what volume of air at 22° C. and 766 mm. pressure would be required?

83. Ten grams of sodium sulphite are dissolved in water. The solution is saturated with sulphur, filtered, and evaporated down to a volume of 12 cc. at 20° C. The solubility of $Na_2S_2O_3, 5H_2O$ is 70 g. in 100 cc. at this temperature. What weight of the salt will be obtained?

84. Five liters of air, measured over mercury at 30° C. and 740 mm. pressure, are placed over water under the same conditions. What will be the apparent volume of the air?

85. A current of 2 amperes was passed through 1 liter of a molar solution of copper sulphate for one hour and 20 minutes. What weight of copper per cubic centimeter did the solution then contain?

86. What volume will 5 g. of nitric oxide occupy over water at 20° C. and 762 mm. pressure?

87. What weight of sodium nitrite must be heated with ammonium chloride to obtain 12 liters of nitrogen measured over water at 18° C. and 790 mm. pressure?

88. By experiment it was found that 1.7268 g. of a certain

substance, when vaporized at 100° C. and 731 mm. pressure, occupied a volume of 139.4 cc. From these facts calculate the molecular weight of the substance.

89. What weights of nitric and hydrochloric acids are necessary to make enough aqua regia to dissolve 5 g. of gold? Concentrated hydrochloric acid has a specific gravity of 1.2 and contains 39% of hydrogen chloride; the corresponding data for nitric acid are 1.42 and 68%. What volumes of the two liquids should be used?

90. It was found that it required 1.032 g. of phosphorus to remove completely the oxygen from 5.185 liters of air measured over water at 20° C. and 750 mm. pressure. The remaining dry gases occupied a volume of 3.725 liters over mercury at N.T.P. What per cent by volume of the dry air was oxygen, and what oxide of phosphorus was formed?

91. Calculate the weights of sand and coke required to produce one ton of 2000 lbs. of phosphorus in the electric furnace.

92. One gram of zinc is dissolved in 500 cc. of sulphuric acid having a specific gravity of 1.1 and containing 16% of the solute. What volume of hydrogen at 15° C. and 735 mm. pressure can be collected over water? What volume of 0.5678 N sodium hydroxide would be needed to neutralize the acid which remains?

93. If the G.M.V. of dry air at N.T.P. weighs 28.9 g., what will be the difference in the weight of the air in a room $5 \times 6 \times 4$ meters in size, when the humidity is 85%? The temperature is 20° C. and the pressure is 751 mm.

94. What weight of sodium pyrophosphate can be made by heating 25 g. of disodium hydrogen phosphate?

95. What weights of manganese dioxide and of sodium chloride are required to produce 1.5 liters of chlorine measured at 15° C. and 770 mm. pressure?

96. If salt is treated with sulphuric acid to form sodium bisulphate and hydrogen chloride, what weight of sodium chloride must be used to prepare 5 liters of hydrochloric acid containing 39% and having a specific gravity of 1.2?

97. (*a*) How many kiloliters of carbon dioxide will result

from the combustion of liquid acetylene, C_2H_2 (sp. gr., 0.8), contained in a cylindrical tank 15 cm. in diameter and 18 dm. high? (*b*) If the carbon dioxide were absorbed by limewater, how many kilograms of calcium carbonate would form? (*c*) How many days will this tank of acetylene serve to light a house having six gas jets, each burning $\frac{1}{2}$ cu. ft. of gas per hour, five hours a day? (1 cu. ft. = 27,000 cc.).

98. Five liters of a mixture consisting of $\frac{2}{3}$ hydrogen and $\frac{1}{3}$ arsine are burned. What weight of water is formed? What weight of arsenious oxide is obtained?

99. What should be the freezing point of a solution of sulphuric acid containing 16% of the solute and having a density of 1.1, if the acid is 90% ionized at this dilution?

100. A solution of copper sulphate is electrolyzed with copper electrodes by a current of 3 amperes for 2 hours and 22 minutes. What will be the increase in weight of the cathode? If the solution contained 44.91 g. of copper per liter, and the electrodes were of platinum, after 500 cc. of the solution had been electrolyzed and treated with excess potassium iodide, what volume of N/10 sodium thiosulphate would be needed to react with the liberated iodine?

ATOMIC WEIGHTS, 1925

(J. A. C. S., Vol. 47, p. 600, 1925)

O = 16.000

Name	Symbol	Atomic Weight	Name	Symbol	Atomic Weight
1. Aluminum	Al	26.97	43. Mercury	Hg	200.61
2. Antimony	Sb	121.77	44. Molybdenum	Mo	96.0
3. Argon	A	39.91	45. Neodymium	Nd	144.27
4. Arsenic	As	74.96	46. Neon	Ne	20.2
5. Barium	Ba	137.37	47. Nickel	Ni	58.69
6. Bismuth	Bi	209.00	48. Niton (Radon)	Rn	222.0
7. Boron	B	10.82	49. Nitrogen	N	14.008
8. Bromine	Br	79.916	50. Osmium	Os	190.8
9. Cadmium	Cd	112.41	51. Oxygen	O	16.000
10. Calcium	Cs	132.81	52. Palladium	Pd	106.7
11. Cesium	Ca	40.07	53. Phosphorus	P	31.027
12. Carbon	C	12.000	54. Platinum	Pt	195.23
13. Cerium	Ce	140.25	55. Potassium	K	39.096
14. Chlorine	Cl	35.457	56. Praseodymium	Pr	140.92
15. Chromium	Cr	52.01	57. Radium	Ra	225.95
16. Cobalt	Co	58.94	58. Rhodium	Rh	102.91
17. Columbium	Cb	93.1	59. Rubidium	Rb	85.44
18. Copper	Cu	63.57	60. Ruthenium	Ru	101.7
19. Dysprosium	Dy	162.52	61. Samarium	Sa	150.43
20. Erbium	Er	167.7	62. Scandium	Sc	45.10
21. Europium	Eu	152.0	63. Selenium	Se	79.2
22. Fluorine	F	19.00	64. Silicon	Si	28.06
23. Gadolinium	Gd	157.26	65. Silver	Ag	107.880
24. Gallium	Ga	69.72	66. Sodium	Na	22.997
25. Germanium	Ge	72.60	67. Strontium	Sr	87.63
26. Glucinum			68. Sulphur	S	32.064
(Beryllium)	Be	9.02	69. Tantalum	Ta	181.5
27. Gold	Au	197.2	70. Tellurium	Te	127.5
28. Helium	He	4.00	71. Terbium	Tb	159.2
29. Holmium	Ho	163.4	72. Thallium	Tl	204.39
30. Hafnium	Hf	180.8	73. Thorium	Th	232.15
31. Hydrogen	H	1.008	74. Thulium	Tm	169.4
32. Indium	In	114.8	75. Tin	Sn	118.70
33. Iodine	I	126.932	76. Titanium	Ti	48.1
34. Iridium	Ir	193.1	77. Tungsten	W	184.0
35. Iron	Fe	55.84	78. Uranium	U	238.17
36. Krypton	Kr	82.9	79. Vanadium	V	50.96
37. Lanthanum	La	138.9	80. Xenon	Xe	130.2
38. Lead	Pb	207.20	81. Ytterbium	Yb	173.6
39. Lithium	Li	6.940	82. Yttrium	Yt	88.9
40. Lutecium	Lu	175.0	83. Zinc	Zn	65.38
41. Magnesium	Mg	24.32	84. Zirconium	Zr	91
42. Manganese	Mn	54.93			

FOUR PLACE LOGARITHMS

No.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6386	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

FOUR PLACE LOGARITHMS—*Continued*

No.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7992	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	2	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

TEMPERATURE CONVERSION

Centigrade to Fahrenheit

Note.—The boxes contain the Fahrenheit temperatures corresponding to the Centigrade temperatures indicated in the columns.

	0	1	2	3	4	5	6	7	8	9	
0	32	33.8	35.6	37.4	39.2	41.0	42.8	44.6	46.4	48.2	
10	50.0	51.8	53.6	55.4	57.2	59.0	60.8	62.6	64.4	66.2	
20	68.0	69.8	71.6	73.4	75.2	77.0	78.8	80.6	82.4	84.2	
30	86.0	87.8	89.6	91.4	93.2	95.0	96.8	98.6	100.4	102.2	
40	104.0	105.8	107.6	109.4	111.2	113.0	114.8	116.6	118.4	120.2	
50	122.0	123.8	125.6	127.4	129.2	131.0	132.8	134.6	136.4	138.2	
60	140.0	141.8	143.6	145.4	147.2	149.0	150.8	152.6	154.4	156.2	
70	158.0	159.8	161.6	163.4	165.2	167.0	168.8	170.6	172.4	174.2	
80	176.0	177.8	179.6	181.4	183.2	185.0	186.8	188.6	190.4	192.2	100
90	194.0	195.8	197.6	199.4	201.2	203.0	204.8	206.6	208.4	210.2	212

0.1° C. = 0.18° F. —273° C. = absolute zero = —459.4° F.

Negative Centigrade Temperatures

	0	1	2	3	4	5	6	7	8	9
0	32	30.2	28.4	26.6	24.8	23.0	21.2	19.4	17.6	15.8
10	14.0	12.2	10.4	8.6	6.8	5.0	3.2	1.4	—0.4	—2.2
20	—4.0	—5.8	—7.6	—9.4	—11.2	—13.0				

TEMPERATURE CONVERSION

Fahrenheit to Centigrade

Note.—The boxes contain the Centigrade temperatures corresponding to the Fahrenheit temperatures indicated in the columns.

	0	1	2	3	4	5	6	7	8	9	
0	−17.8	17.2	16.7	16.1	15.6	15.0	14.4	13.9	13.3	12.8	
10	−12.2	11.7	11.1	10.6	10.0	9.4	8.9	8.3	7.8	7.2	
20	− 6.7	6.1	5.6	5.0	4.4	3.9	3.3	2.8	2.2	1.7	
30	− 1.1	0.6	0.0	+0.6	+1.1	1.7	2.2	2.8	3.3	3.9	
40	+ 4.4	5.0	5.6	6.1	6.7	7.2	7.8	8.3	8.9	9.5	
50	10.0	10.6	11.1	11.7	12.2	12.8	13.3	13.9	14.4	15.0	
60	15.6	16.1	16.7	17.2	17.8	18.3	18.9	19.4	20.0	20.5	
70	21.1	21.7	22.2	22.8	23.3	23.89	24.4	25.0	25.6	26.2	
80	26.7	27.2	27.8	28.3	28.9	29.4	30.0	30.6	31.1	31.6	100
90	32.2	32.8	33.3	33.9	34.4	35.0	35.6	36.1	36.7	37.3	37.8

0.1° F. = 0.06° C. −459.4° F. = absolute zero = 273° C.

Negative Fahrenheit Temperatures

	0	1	2	3	4	5	6	7	8	9
0	−17.8	18.3	18.9	19.4	20.0	20.6	21.1	21.7	22.2	22.8
10	−23.3	23.9	24.4	25.0	25.6	26.1	26.7	27.2	27.8	28.3

Fahrenheit Temperatures Above 100

	0	5	10	15	20	25	30	35	40	45
100	37.8	40.6	43.3	46.1	48.9	51.7	54.4	57.2	60.0	62.8
150	65.6	68.3	71.1	73.9	76.7	79.4	82.2	85.0	87.8	90.6
200	93.3	96.1	98.9	101.7	104.4	107.2	110.0	112.8	115.6	118.3

VAPOR TENSION OF WATER FROM 0°–39° C.

Adapted from the International Bureau of Weights and Measures. (The boxes contain the aqueous tension in mm. of mercury for the temperatures in the columns)

	0	1	2	3	4	5	6	7	8	9
0	4.57	4.91	5.27	5.66	6.07	6.51	6.97	7.47	7.99	8.55
10	9.14	9.77	10.43	11.14	11.88	12.67	13.51	14.40	15.33	16.32
20	17.36	18.47	19.63	20.86	22.15	23.52	24.96	26.47	28.07	29.74
30	31.51	33.37	35.32	37.37	39.52	41.78	44.16	46.65	49.26	52.00

THE METRIC SYSTEM

WITH SOME ENGLISH EQUIVALENTS

	Length	Area	Volume	Weight (Mass)
1000 Units	Kilometer, Km. =0.621 mile		Kiloliter, Kl. =1 cu. m. =35.3 cu. ft. =1.308 cu. yds.	Kilogram, Kg. =2.205 pounds (avoir.)
100 Units	Hectometer, Hm.	Hectare, Ha. =10,000 sq. m. =2.47 acres	Hectoliter, Hl. =2.838 bushels	Hectogram, Hg.
10 Units	Dekameter, Dm.		Dekaliter, Dl. =1.135 U. S. pecks	Dekagram, Dg.
Unit	Meter, m. =39.37 inches	Are, a. =100 sq. m. =1076 sq. ft.	Liter, l. =1000 cu. cm. =1.057 U. S. liq. quarts =0.908 U. S. dry quart	Gram, g. =wt. of 1 cu. cm. H_2O =0.0353 ounce (avoir.)
0.1 Unit	Decimeter, dm.		Deciliter, dl.	Decigram, dg. =1.543 grains
0.01 Unit	Centimeter, cm.	Centare, Ca. =1 sq. m. =10.76 sq. ft.	Centiliter, cl.	Centigram, cg.
0.001 Unit	Millimeter, mm.		Milliliter, ml. =1 cu. cm. =0.0610 cu. inch =0.0338 U. S. liq. ounce	Milligram, mg.

METRIC EQUIVALENTS OF ENGLISH UNITS

Length

1 inch = 2.54 cm.
1 yard = 0.914 m.
1 mile = 1.61 km.

Area

1 sq. inch = 6.45 sq. cm.
1 sq. yard = 0.836 sq. m.
1 sq. mile = 2.59 sq. km.

Volume

1 cu. inch = 16.39 cu. cm.
1 cu. foot = 0.0283 cu. m.
1 cu. yard = 0.765 cu. m.

Weight

1 ounce = 28.35 g.
1 pound = 0.4536 Kg.
1 short ton = 907 Kg.

P9-CXM-799